METALLURGIA

THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER"

FEBRUARY, 1954 Vol. XLIX. No. 292

Corrosion Education

IT has been estimated that the annual expenditure on the protection of iron and steel against corrosion, in Great Britain alone, amounts to some £200 million. The figure is based on the cost of applying two coats of paint to the whole of the steel produced each year, and while it may be argued that not all of it requires painting—a figure of 75% has been quoted—extensive repainting of existing steelwork is also necessary. Moreover, for certain types of service, special protective measures may be called for which are more costly than painting. Whatever the true figure, there can be no doubt that it is enormous, and, as corrodibility is not peculiar to ferrous metals, any assessment of the economic consequences of the fact that metals corrode must take into account the non-ferrous metals.

From whatever point of view one looks at it, corrosion is a retrograde process. The engineer represents construction—corrosion represents destruction : the metallurgist busies himself with the extraction of metals from their compounds—corrosion busies itself with the reversion of metals to compounds ; sometimes, as in the case of iron, to a form very similar to that from which it was originally won.

The corrosion of metals presents problems of interest to the chemist, the metallurgist and the engineer, and much thought and effort have been put into attempts to find satisfactory solutions to them. The work has ranged from theoretical studies of the mechanism of corrosion to field trials of a new range of paints, and whilst our fundamental knowledge has increased enormously as a result of this work, and whilst we now know some of the answers to the practical problems, there is still tremendous scope for workers in this field. The experimental work is by no means easy, as the variables to be considered are so numerous that tests under controlled conditions require much though in planning and careful experimentation in execution. Furthermore, whilst accelerated corrosion tests may provide useful pointers in the development of corrosion resistant materials and coatings, it is the lengthy field trial which provides the necessary confirmation.

The forces responsible for progress in many fields are economic, and corrosion is no exception, its importance as an economic problem having been increasingly appreciated during the last two decades. In consequence, there has been a more widespread study of its problems, and more and more workers have joined in the attack. Largely as a result of this growing interest, the corrosion Group of the Society of Chemical Industry was formed in 1951, to fill the need for a scientific society in the United Kingdom to deal specifically with the study of corrosion and its prevention. The Group arranges technical meetings in London and the provinces, and, at least once a year, a full day symposium is organised to discuss some particularly important aspect, such as caustic cracking, corrosion inhibitors and cathodic protection—to name those already held. Apart from the provision of a means of communication among those concerned with corrosion, and the stimulation of general interest in the need for a scientific study of the subject, the Group aims at encouraging the application in industry of improved methods of prevention. In addition, it has established an Education Panel to promote training in science corrosion.

There is an old saying that prevention is better than cure, and of nothing is this more true than of corrosion. It is in this respect, therefore, that the Group may exercise its most important function as far as industry generally is concerned. There have been media for the publication of corrosion work before, but there has not previously existed an informed body of opinion interested in corrosion and appreciative of its technical and economic significance. Much good could come of a crusade, on the part of the Group, to dispel the—in some cases abysmal—ignorance that exists on the subject. The exhibition held at Battersea Polytechnic last month, and referred to elsewhere in this issue, which was designed to portray some of the most important methods and processes for preventing the corrosion of iron and steel, was a step in the right direction.

It was on that occasion that the Chairman of the Group, Dr. J. C. Hudson, pointed out that although there was much to learn, the application of existing knowledge about corrosion protection could achieve annual savings running into millions of pounds. There, then, is a measure of the need for a campaign of enlightenment. If further support is needed, there come to mind numerous examples of designs which even an elementary knowledge of the subject would have condemned from the start. There was a case of a street lighting lantern, put into service in a coastal area, with glass sides supported by copper channels fixed to cast aluminium alloy end plates by brass screws—an ideal corrosion-promoting combination. Quite recently, too, a proposed design for a street shelter incorporated dissimilar metals in such a way that attack would have been inevitable. Nor is it only in the use of dissimilar metals that designers err ; many structures would be much less susceptible to corrosive attack if they were re-designed to avoid the presence of lodging places for water, crevices where solutions can concentrate, and similar objectionable features. Of course, the ideal design may be impossible of achievement, in which case a compromise has to be sought which will minimise the danger.

These purely design features may prove to be the most difficult to get across, as they are not backed by any publicity on the part of manufacturers, as is the case with protective coating processes. Even there, however, educational work could be undertaken to advantage to help the designer to judge between one method and another, having regard to the service conditions likely to be encountered.

March Diary

1st

Institute of British Foundrymen—Sheffield Branch. "Methods Employed in the Production of Heavy Iron Castings," by J. Richardson and F. C. Lawson. Sheffield College of Commerce and Technology, Department of Engineering, Pond Street, Sheffield, 1. 7-30 p.m.

2nd

Institute of Fuel—Midland Section. "Flow Patterns in Furnaces," by M. J. McInerney. Joint Meeting with the North Staffs. Fuel Society. Lecture Room of the Midlands Electricity Board, Kingsway, Stoke-on-Trent. 7 p.m.

Institute of Metals—Oxford Local Section. "Thermochemistry of Alloys," by Dr. A. R. Harding. Oak Room, Cadena Cafe, Cornmarket Street, Oxford. 7 p.m.

Institute of Metals — South Wales Local Section. "Alumino-Thermic Methods," by T. Burchell. University College, Metallurgy Department, Singleton Park, Swansea. 6-45 p.m.

Sheffield Metallurgical Association. "Aspects of Optical and Electron Microscopy," by Dr. J. Nutting and G. C. Smith. B.I.S.R.A., Hoyle Street, Sheffield. 7 p.m.

3rd

Institute of British Foundrymen—Burnley Section. Annual General Meeting and Election of Officers. Followed by a short paper. Municipal College, Ormerod Road, Burnley. 7-30 p.m.

Manchester Metallurgical Society. "Surface Finishing by Liquid Honing," by D. V. Grant. Lecture Room, Central Library, Manchester. 6-30 p.m.

North East Coast Institution of Engineers and Shipbuilders. Student Section. "A Brief Review of Stress Concentration and Fatigue Failure," by I. E. Telfer. Bolbec Hall, Newcastle-upon-Tyne. 6-45 p.m.

4th

East Midlands Metallurgical Society. "Experimental Welding of Metallurgical and Engineering Interest," by B. R. Byrne. Nottingham and District Technical College, Shakespeare Street, Nottingham. 7-30 p.m.

Incorporated Plant Engineers—Peterborough Branch. "Welding for Maintenance," by J. S. Skelton. Eastern Gas Board's Demonstration Theatre, Peterborough. 7-30 p.m.

Institute of Fuel—Scottish Section. "Flame Propagation and Radiation," by Professor M. W. Thring. Royal Technical College, Glasgow. 7 p.m.

Institute of Metals—Birmingham Local Section. "Metals in the Oil Industries." Arranged by Shell-Mex and B.P. Ltd. James Watt Memorial Institute, Great Charles Street, Birmingham, 6-30 p.m.

Institute of Metals—London Local Section. "High Temperature Corrosion," by Dr. J. P. Dennison. 4, Grosvenor Gardens, London, S.W.1. 6-30 p.m.

Leeds Metallurgical Society. "Applications of Aluminium and its Alloys," by J. C. Bailey. Chemistry Department, The University, Leeds, 2. 7-15 p.m.

5th

Society of Chemical Industry—Corrosion Group. "Protective Coatings for Ships and Marine Installations, by J. C. Hudson; "Cathodic Protection of Ships and Jetties," by K. A. Spencer; "Corrosion of Ships' Machinery," by L. Kenworth; "Performance of Aluminium Alloys in Ships," by D. C. G. Lees. (Joint Meeting with the Glasgow Section.) Royal Technical College, George Street, Glasgow, C.1. 2-30 p.m. and 7-15 p.m. (It is hoped to arrange a visit to a Shipyard for the morning of March 5th.)

6th

Institute of British Foundrymen—Lancashire Branch. "Inter-relation of Combustion and Metallurgical Reactions in, the Cupola," by D. Fleming. Engineers' Club, Albert Square Manchester. 3 p.m.

8th

Institute of Metals—Scottish Local Section. "Powder Metallurgy," by Dr. D. D. Howat. Institution of Engineers and Shipbuilders in Scotland, 39, Elmbank Crescent, Glasgow, C.2. 6-30 p.m.

Institute of Welding—Sheffield and District Branch. "Technical Institutions, their Organisation and Functions," by G. A. Parsloe. Sheffield College of Commerce and Technology, Pond Street, Sheffield. 7-15 p.m.

Junior Institution of Engineers—Sheffield and District Section. "The Use of High Frequency Heating in the Metallurgical Industry," by J. B. Ingall. Livesey Clegg House (opposite Union Street Cinema), Sheffield. 7-30 p.m.

9th

Institute of British Foundrymen—Birmingham and West Midlands Students' Section. Works Visit to F. H. Lloyd and Co. Ltd., Near Wednesbury. 2-30 p.m.

Institution of Engineers and Shipbuilders in Scotland. "Ships' Lifts," by J. Austwick and S. T. Elvy. 39, Elmbank Crescent, Glasgow. 6-45 p.m.

10th

Institute of Fuel—North Western Section. "The Design and Operation of Small Water-tube Boilers," by G. Steward. Engineers' Club, Albert Square, Manchester. 2 p.m.

Institution of Engineering Inspection—Wolverhampton Branch. "Engineering Applications of Electro Deposited Metals," by J. W. Oswald. Compton Grange, Compton Road, Wolverhampton. 7-30 p.m.

11th

Incorporated Plant Engineers—Sheffield and District Branch. General Discussion on Maintenance Problems. Grand Hotel, Sheffield. 7-30 p.m.

Institute of British Foundrymen—Lincolnshire Branch. "Mechanical Aids to Production," by H. Hadan. Lincoln Technical College, Lincoln. 7-15 p.m.

Liverpool Metallurgical Society. "Titanium—a Metal of Engineering Importance?" by Major P. L. Teed. Liverpool Engineering Society, The Temple, Dale Street, Liverpool, 7 p.m.

12th

Institute of British Foundrymen—Southampton Section. "Propeller Manufacture," by J. Langham. Southampton Technical College, St. Mary Street, Southampton. 7 p.m.

13th

Institute of British Foundrymen—Scottish Branch. "Variety Production in a Jobbing Foundry," by C. B. Scarcliffe. Royal Technical College, George Street, Glasgow. 2-45 p.m.

Institute of British Foundrymen—West Riding of Yorkshire Branch. "Nodular Cast Iron," by M. M. Hallett. Technical College, Bradford. 6-30 p.m.

15th

Joint Meeting of Sheffield Society of Engineers and Metallurgists and Institute of Metals—Sheffield Local Section. "Some Factors Affecting Spring Design," by Dr. W. R. Berry. University Building, St. George's Square, Sheffield. 7-30 p.m.

16th

Institute of British Foundrymen—Coventry and District Students' Section. "A Review of Progress in the Technical Development of Cast Iron," by Dr. A. B. Everest. Coventry Technical College, Room A.5. 7-15 p.m.

Institute of British Foundrymen—East Anglian Section. Paper by G. M. Taylor. Central Hall, Public Library, Ipswich. 7-30 p.m.

Institute of Metals—South Wales Local Section. Annual General Meeting. University College, Metallurgy Department, Singleton Park, Swansea. 6-45 p.m.

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Faults in Pressure Die Castings—II

By W. M. Halliday

The factors influencing the quality of pressure die castings are many and varied, ranging from die design to the metallurgical characteristics of the alloy used. The main types of fault include dimensional inaccuracy, poor surface and mechanical weakness. In the present article, the author deals with faults in the last two categories.

THE first part of this article, published last month, was concerned with the causes and means of prevention of dimensional inaccuracies in die castings. A further group of faults is dealt with in the following pages, namely, those affecting the appearance and surface finish of the castings. Generally speaking, these are the most numerous, yet the least serious, class of defects, as will be seen from the details given below. In many instances, the remedial treatment is apparent.

Surface Defects

(a) General Inferior Surface Finish

Failure to obtain a satisfactory general surface finish and smoothness may be due to the poor quality finish imparted to the cavity wall surfaces of the die. Tool marks, scratches, burrs, minute nicks, etc., are all faithfully reproduced on the casting, and may show on important outer or inner surfaces as unsightly blemishes. In some cases, small dies are not hardened, and such tools are especially liable to suffer damage during use.

This faithful reproduction of the surface finish on the cavity walls is due to the high injecting pressures and velocities employed in modern die-casting machines. The injected metal stream is packed forcibly against the walls and core surfaces in the cavity area. These parts are also the first to chill and solidify, and this feature constitutes one of the chief merits of the pressure die casting, in that it gives a wall structure having a hard, dense, and tough outer skin bounding a softer core. This form of wall structure explains why thin wall sections are to be preferred; they are relatively much stronger than thick ones. The casting conditions also ensure that important surfaces of the casting are formed with great accuracy and definition. Really intricate configurations and sharp corners can also be produced with greater ease.

Sometimes surface blemishes that are generally distributed over large areas of the casting may be caused by hardening scale remaining on the cavity walls. Furthermore, with certain alloys, notably aluminium, there may be some tendency for oxide accumulations to build up on or adhere to the walls of the cavity. This can be seen in the die cavity as a hard dull grey or whitish scale, a deposit which cannot be melted off at the temperature of the molten alloy. Usually such a scale is found to adhere tenaciously to a slightly roughened surface of the steel die. The same undesirable die defect may be caused by overheating the tool at some point, so causing excessively rapid oxidation of the metal charge. Usually this condition arises where exceedingly thin wall sections are formed in the die.

All tool marks, nicks, burrs, scratches, scale and oxide on the die should be polished away, and a chromium-plated finish may be usefully applied in some cases as a further protection. Care must also be taken in the selection of die steels. If the wrong grade is used, it may be found that "checking" or "surface cracking" speedily occurs when the die is subjected to the working conditions. If the die is over-hardened, or the tool is used with the higher melting-point alloys; or if very high injection pressures and velocities are employed; or if the die temperature is allowed to fluctuate greatly during use; minute surface cracks and heat checking of the die surface may take place.

In its early stages, this condition is distinguished by the presence of innumerable minute hair-like lines radiating in all directions. Such impressions may only be raised a fraction of a thousandth of an inch above the normal surface of the casting, and thus may easily be removed by the customary polishing or mopping operations. Later, as the condition in the die becomes more aggravated, the cracks enlarge in size and extent, and give rise to very clearly defined raised projections on the casting.

Very little can be done to effect a permanent cure of this condition. Some amelioration may, however, be obtained by regular inspections of the die, and frequent polishing of the affected surfaces.

(b) Rough Patches

These are generally located at certain points on the surface of the casting, and are similar in each successive casting. The patch may be extensive or very limited in area, being very slightly raised above the surface of the casting, but the degree of roughness may vary considerably.

These patches are often relatively unimportant, except where the casting has to be supplied in self-colour, or with a high gloss electroplated finish. They can often be removed quite simply by ordinary polishing or sanding means, and rarely involve any weakening of the structure of the casting, being purely a surface defect.

The condition may arise from several causes. First, there may be some accumulation built-up on the cavity surface. In practice, use of unsuitable die lubricants and cavity wall washes is one common cause of such build-up. Variations in the thermal condition of the die may also produce similar effects. If certain portions are improperly water-cooled and allowed to reach a very high temperature, surface oxidation may occur when the alloy is injected into the overheated portion of the die.

The appropriate corrective treatments are readily apparent.

(c) Flow Marks

These are sometimes known as "flowers" or "orange-peel." They are usually unimportant surface blemishes, generally capable of being easily, and often entirely,

removed by ordinary polishing methods. They consist of numerous lines, which often radiate from the gate location point. In certain instances the marks are very faint, whilst in others strongly defined. The lines may, in some cases, appear to take a regular form or pattern, but often are distinguished as slightly mottled or faintly striated surfaces on the casting. Flow marks are exceedingly shallow, rarely reaching a depth of more than one or two ten-thousandths of an inch, and, in consequence, they result in no weakening of the casting. Examination shows that the internal structure is usually quite sound and homogeneous.

Several factors may contribute to this condition, but the most frequent causes include insufficient injection pressure; unsuitable location of gates; excessive turbulence in the die cavity; and film formation between the cavity walls and the outer skin of the casting on solidification. The latter condition may frequently arise because of the use of unsatisfactory coating substances or die lubricants. The film may, indeed, result from a slight vapour production from moisture absorbed in the die wash.

Generally, an increase in the injection pressure or better location of the gate are the best correctives.

A typical example showing a surface marred by the presence of unsightly flow marks, is illustrated in Fig. 1. This is a circular ring component in zinc-base alloy, one side of which has several narrow recesses, certain raised bosses, and a number of small-diameter cored holes, as well as the large hole through the centre.

Flow marks in the form of a mass of lines and striations occur on the surface, the lines tending to run radially from the periphery to the centre hole; they give a good indication of the turbulence taking place in the flowing metal in the cavity. The gate channel is so located as to feed into the periphery of the ring, with the width of gate extending over a very short arc. Owing to the large hole in the centre, and the fixed core plug needed in the die, the stream cannot travel far before striking the core, and, thereby, suffering considerable diversion and turbulence.

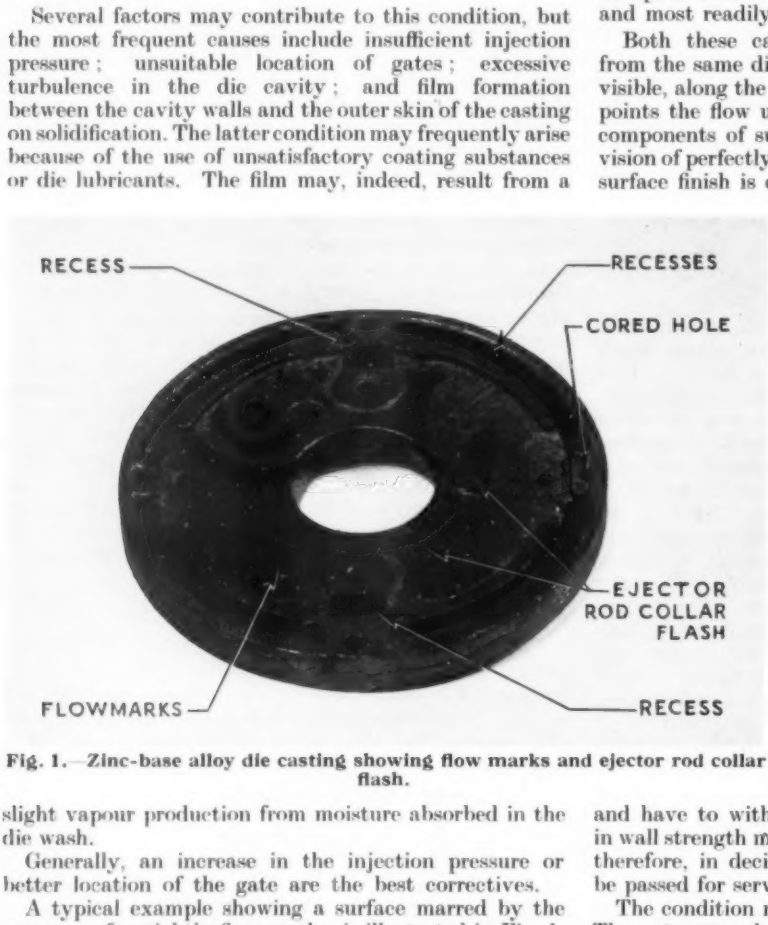

Fig. 1.—Zinc-base alloy die casting showing flow marks and ejector rod collar flash.

Ejector collar flash markings are also plainly visible at four points on this side of the casting. In two cases ejector rods had been improperly set in the die, leading to the formation of slightly raised bosses on the part. Incidentally, such flash rings would be difficult to remove inexpensively, owing to their location upon the floor of the large diameter recess, the flat surface of which is intersected by two bosses.

In Fig. 2, two castings in zinc-base alloy, forming a simple hinge device, illustrate the good surface finish possible by freedom from flow marks, even with perfectly flat plain surfaces, which are notoriously uninteresting and most readily show any minor imperfections.

Both these castings were produced simultaneously from the same die, and only the faintest flow marks are visible, along the roots of the cylindrical bosses, at which points the flow undergoes a change in direction. With components of such simple geometrical shape, the provision of perfectly regular cavity walls, with the smoothest surface finish is comparatively easy and inexpensive.

(*d*) *Seam Lines*

These are somewhat similar to flow lines, but of course much deeper. Unlike the widely distributed flow mark, the seam line is usually confined to one specific area on the casting, and recurs in substantially the same position at each shot. This defect, of course, is often difficult to remove by conventional polishing means, and, moreover, it may be the source of some weakness in thin walled castings.

It is caused by a combination of factors, such as insufficient injection pressure, coupled with the trapping of gas at certain points in the cavity area. Turbulence in the cavity may also be a contributory cause of this condition. Incorrect location of the gate may sometimes give rise to seam lines of this kind, but other factors are also usually present.

When thin-walled parts of a casting contain this seam irregularity, and have to withstand pressure tests, some weakening in wall strength may be noted. Care should be exercised, therefore, in deciding which faulty components should be passed for service use.

The condition may be corrected in a number of ways. The gates may be modified, or relocated so as to feed the cavity from another direction, and air venting channels may be provided in the die. Alternatively, overflow wells may be inserted in the die adjacent to the region of the main cavity affected by seams, so that any gases are displaced by the flowing alloy charge into such sub-cavities. The injection pressure may also be increased to assist elimination of air from the cavity.

Fig. 3 shows a three-bladed propeller in Mazak No. 3 alloy, and illustrates the undesirable effects on surface finish and mechanical strength arising from the presence of seams, etc.

The finish on all three blade sections, especially the nearest one, and on the sides of the centre boss is exceedingly poor, due to several large seam patches, where the material layers have failed to weld smoothly and

uniformly. Such seams take the form of well-defined patches occurring more or less in the same positions on successive castings. The effect of such faults is three-fold; to mar appearance; to weaken blades; and to produce irregularity of outline at the thin feathered edges of the blades.

With the die producing this propeller, the causes of such seam formations were four, namely, poor gate location; inadequate air-venting; unequalised die heat; and low velocity of the incoming charge.

Because of the difficult shape of this component, and the inclined "set" to be imparted to each blade, gating of the die presented certain problems. The best results were obtained by employing two gates from a branched runner, feeding into two adjacent blades, rather than a single gate feeding into the centre boss. Gating of this latter kind was, however, the most convenient for linking with the main runner channel, and subsequent flash removal.

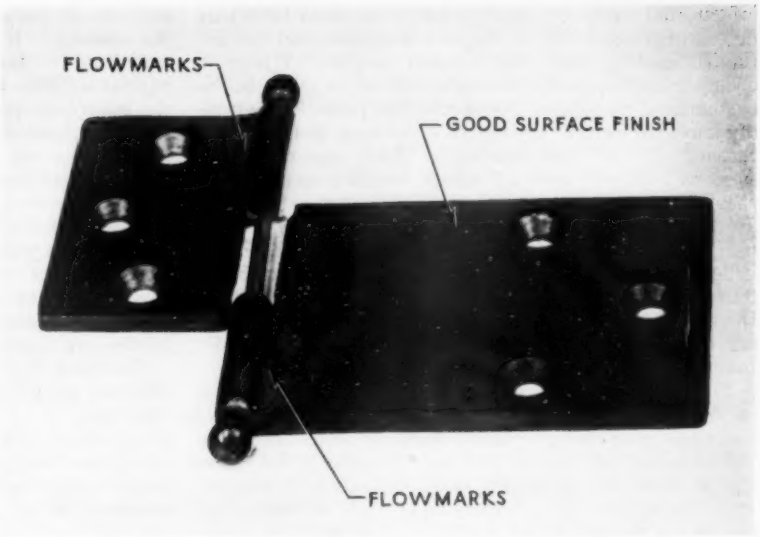

Fig. 2.—Two zinc-base alloy die castings showing good finish on flat surfaces and faint flow marks in corners.

(e) Minute Pinholes at the Surface

This is one type of porosity, and usually occurs with the higher melting point alloys. It may not only mar the surface finish, but it also entails serious weakening of the wall structure. Furthermore, it proves most troublesome if the casting has to be plated or highly polished. Generally, pinholes of this kind are located at, or very near to, the surface, and may be restricted to one or two particular spots. A large number of these minute openings may be present to form a large patch. Viewed through a magnifier, the pinholes can be seen to penetrate for an appreciable depth, so that a cursory visual inspection may fail to give a true picture of the extent and seriousness of this condition, which should always be viewed with some suspicion, inasmuch as the strength of the part may be affected.

Furthermore, care is required when polishing the part, or when applying surface finishes. Removal of even a very slight amount of stock from the surface may cause a noticeable apparent extension of the affected area, because of the uncovering of further pinholes normally lying underneath the surface skin. This condition creates difficulties for the plater, and for the machinist having to drill holes at the affected spots.

This fault can be caused by trapped air pockets in the cavity; by gas inclusions carried through by the charge; or by the generation of gases in the cavity as a result of burning off the lubricant. Insufficient injection pressure may also be an important contributory cause.

Remedial treatment should include the improved venting of the die, either by re-locating the vent relative to the position of air pockets trapped in the cavity, or by increasing the capacity of such vents. Provision of overflow wells may prove helpful, but care is required in determining the position of such elements: the injection pressure may also be increased to useful effect. Some attention should be given to the die temperature to ensure that it is reasonably uniform throughout the cavity so that premature chilling is minimised.

(f) Surface Cracking.

This form of surface defect consists of large numbers of tiny cracks, of hair-like magnitude, appearing at certain spots on the surface skin of the casting; usually

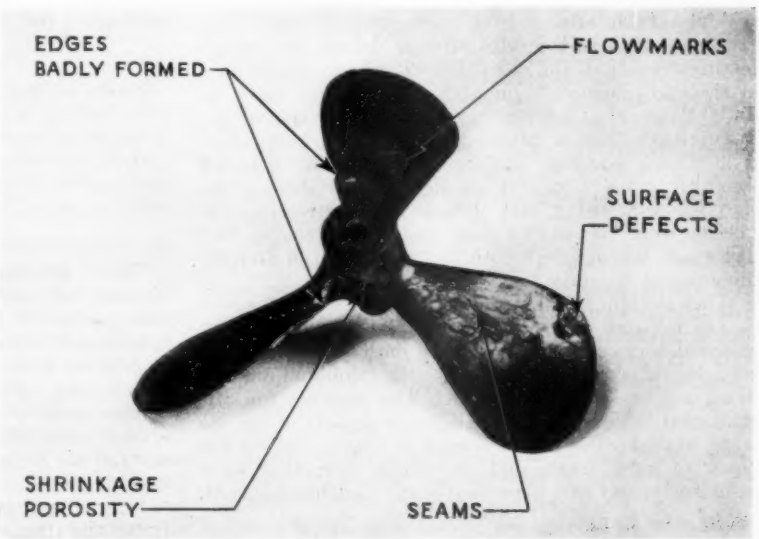

Fig. 3.—Zinc-base alloy die cast propeller showing a selection of surface defects.

on external surfaces. In its most pronounced form this defect may constitute a distinct weakness and render the component unfit for stressed service. Where it occurs to any appreciable depth, difficulties may also be encountered in polishing or plating the parts. This type of defect is usually restricted to certain areas on the casting, e.g., at the junction of thick and thin wall sections; at the root of heavy bosses; adjacent to sharp corners; and along the base of heavy section ribs.

It is usually due to unequalised shrinkage, or to the use of cores having insufficient ejection draft. A feature which often makes this fault difficult to diagnose is the tendency for cracks to develop after the casting has left the die. This tendency may often be aggravated by the use of an unsuitable ejector system, and, especially by inappropriate location of the ejector rods.

The condition may sometimes be caused by the use of the wrong kind of die coating. One of the chief functions performed by a die dressing is to act as an insulator and prevent the too rapid transfer of heat from the walls of the die cavity most intimately in contact with the molten alloy charge. If such an insulating dressing is very unevenly applied, certain portions of the cavity wall will remove heat at a much quicker rate than the remaining portions. That portion of the alloy charge in contact with the improperly insulated wall, will solidify first, and in shrinking will tend to draw metal away from those areas where the metal cools more slowly because of the better insulation provided on the cavity wall. The pressures set up by drawing-off metal from already chilled portions may be very great, and the resultant high stressing of the partially formed casting may cause slight rupture of the surface skin at, or close to, those points where the wall is weakest, or where the greatest opposition to such movement is offered by cores.

(*g*) *Flash.*

Flash is a very common and sometimes unavoidable fault. For example, some flash almost always occurs at the die parting line; where the gate leads into the wall; where ejector rods impinge upon the surface of the casting; and where movable core plugs break into the cavity wall, etc.

Whilst flash arising from such sources may often cause a certain amount of trouble during the actual casting operation, the chief difficulties are usually met in trying to remove it in such a way as to leave no unsightly scar. Care has also to be taken during the casting operation to guard against the development of flash of such thickness that the casting cannot be ejected smoothly, uniformly, and quickly. When this occurs, the increased delay and difficulty in extracting the casting from the cavity may result in cracking and distortion, which affect both the surface finish and the dimensional accuracy.

When evolving a die design, the designer takes care to ensure that all unavoidable flash is located on non-essential surfaces, and also in the most accessible positions for subsequent removal with the minimum amount of machining, setting, or trouble. The tendency towards thickened flash increases as the critical parts of the die wear, so that constant watch must be kept to observe the onset of such wear, and to effect correction at a sufficiently early date to prevent heavy flash being caused.

(*h*) *Surface Sinks.*

Faults of this character often occur as a secondary effect of some more deep-seated internal trouble, such as internal porosity, or grossly uneven contraction of the casting. If certain areas of the die cavity are permitted to become overheated, the metal in those regions solidifies last. Such regions may be isolated from the main high pressure feed flowing into the die, due to the solidification of other parts of the casting, and, on contracting, no compensating feed is available: the metal located in the hottest part of the cavity, therefore, tends to contract from the cavity surface when solidification eventually takes place. The surface skin, thus, loses contact with the cavity wall and "sinks" or hollow depressions occur. Similar conditions may result from the presence of large cores, and the over-rapid chilling effects they may have on the immediately adjacent portions of the casting walls.

The cure for this surface defect lies in the more effective stabilising of temperature throughout the die. This may be accomplished either by using or adapting the normal water-cooling provisions; by applying additional heat to certain portions of the die; or by introducing dummy runner channels around specific areas of the cavity: all designed to give more uniform and balanced heating of the tool.

(*i*) *Scabs and Blisters.*

These faults take the form of slightly raised rough surfaced excrescences occurring on certain portions of the casting surface, and may be caused by several factors. The most frequent cause is the overheated condition of certain parts of the die cavity. This results in retarded solidification of adjacent regions of the casting, and the tearing of the partially chilled skin surface when the casting is ejected. The same condition may sometimes occur as a result of over-quick ejection, before all portions of the casting have solidified.

On occasion, a tiny pocket of trapped air may be present immediately beneath such a hot spot, and on removal of the casting, this trapped air may cause the partially chilled surface skin to be pressed outwards, forming an unsightly raised blister or scab.

Such defects can usually be effectively prevented by improving the gating facilities to ensure quicker filling of the cavity; by providing additional heat to certain portions of the die; or by better venting.

Mechanical Weaknesses

Faults occurring under this heading are generally the most serious in their effects upon the appearance and strength of the component. Often they are much more difficult to correct than those resulting in dimensional inaccuracies or minor surface defects. A few of the more common defects and their causes are now described.

(*a*) *Porosity*

Three different types of porosity are commonly encountered—shrinkage porosity, trapped air porosity and partial-fill porosity—the names indicating their nature and source of origin. Porosity is a condition usually confined to the internal structure of casting walls, but it may, of course, give rise to several secondary defects such as surface sinks, cracks, etc. It almost always constitutes a source of weakness in the casting, as well as being the direct cause of certain other irregularities.

Internal porosity reduces the density of the casting walls, and diminishes the fatigue and impact strengths. If such porosity is combined with a surface sink connected to it by intercrystalline seam cleavage lines, the strength

of the part is still further reduced, and its corrosion resistance adversely affected. The latter effect gives rise to trouble in any subsequent electroplating of the casting. Of the three common forms of porosity, that caused by unequalised shrinkage is the most serious.

Shrinkage porosity most frequently occurs in those regions where there is a sudden change in wall thickness and metal mass, or, alternatively, where there is intense local overheating of the die cavity wall. When the alloy charge is injected into the relatively cool die cavity, a rapid decrease in volume occurs due to the normal shrinkage of the metal. If there is a lack of compensatory pressure feed from the flowing alloy at the gate or adjacent portions to accommodate for such volume contraction, metal has to be drawn from other portions of the casting which have not yet wholly solidified.

Normally, the tendency is for it to be drawn from the heavier and more massive sections, resulting in the creation of a void or porous spot in the internal structure. The high shrinkage and suction forces created by the contracting alloy draw metal from the inner layers of the wall, which are the last to solidify, and in this way the outer skin portions may appear perfectly formed, of the correct shape, and give an appearance of complete solidity to the casting.

The corrective treatment for this form of porosity may entail the relocation of the gating provisions to ensure adequate feed to those areas subject to the greatest amount of shrinkage. Alternatively by re-designing the die it is often possible to eliminate the regions of excessive shrinkage altogether. This may be accomplished by the use of ribs or small bosses, or by a general reduction of wall thickness. Similarly, the die may be vented in a more suitable manner, or may have its working temperature equalised by the more judicious use of the water-cooling provisions.

Sometimes an enlargement of the gate suffices to overcome the condition, by affording a greater flow of fresh molten alloy to critical portions of the cavity, so compensating for shrinkage occurring at those points. Reducing the velocity of the incoming metal charge, and increasing the pressure slightly, may also be found extremely useful in eliminating the trouble.

It is worth noting that this type of porosity generally takes the form of one very large void, or several medium sized ones closely linked together. The shape of such a void is also very irregular, consisting of several deep narrow channels, corners and crevices, which in total constitute a very serious diminution of the wall structure. With trapped-air and partial-fill porosity, however, the void or voids usually have a very regular shape, and are smooth surfaced.

Trapped air porosity is due to pockets of air, gas, or vapour being locked in certain parts of the die cavity, and generally results from unsuitable die design. Whilst it is the least serious of all forms of porosity it may present some difficulties in respect of its elimination.

The correction of the trouble is usually successfully effected by providing suitable air escape channels, and overflow well cavities, into which possible air pockets may be forced ahead of the injected alloy charge.

A difficulty associated with the use of air vents, is that such channels (because of their restricted size) are easily filled with alloy immediately the charge enters the die cavity. Such metal instantly chills and freezes to block up the vents, thereby preventing any further egress of air, and to that extent nullifying their value.

Much can be accomplished by re-designing the die in such a manner as to obviate inaccessible and enclosed pocket formations into which air may be driven and trapped, or by re-gating to give a better direction of flow to and throughout such regions.

Sometimes gases and vapours may be evolved in the die cavity due to presence of a lubricant or die wash. This cause should, of course, be eliminated, and normally it presents no difficulty in diagnosis or correction.

Partial-fill porosity results from the failure of the alloy charge completely to fill the cavity configuration, due to a number of causes. It may easily be confused with trapped-air porosity. The difference between them, however, is that with partial-fill porosity, a sufficient volume of alloy is prevented from reaching all portions of the cavity before the flow ceases, by solidification at the gate, etc., whereas trapped-air porosity is due to reaction pressure arising from locked air, which prevents or retards the complete filling of the cavity.

This condition may be corrected by enlarging the gate and runner capacity, or by relocating the gate to change the direction of flow. Sometimes an increase in the pressure and velocity of the incoming charge is found useful, especially if adopted in conjunction with the previously mentioned remedies.

(*b*) *The Cold Shut.*

Another prevalent and serious irregularity often met with is the "cold shut." This is usually exhibited in the form of a visible seam, parting, or cleavage of the external layer of the casting wall, and it may extend for a considerable distance. One of the chief difficulties associated with this type of fault is that its surface appearance may give a wholly misleading impression of the real magnitude of the defect. At the surface, the cleavage may be extremely slight, in fact often barely discernible by the unaided eye. At lower levels, however, it may be very extensive, and far wider than at the surface.

Close examination of the cold shut usually indicates that two distinct layers of metal have been formed, with an obvious difference in the time of their solidification. Thus, the two layers approximate to two separate castings, superimposed one above the other, and between which no true weld has taken place. In this way, a seam or breakage occurs in the internal structure of the casting wall. It will be obvious that a cold shut of any size is a source of weakness, and, therefore its repeated occurrence on successively produced castings should be viewed with concern and immediate steps taken to correct the condition. Generally, the cold shut is evidence of very unsuitable casting conditions associated with the die.

This fault may generally be eliminated quite successfully by one or all of the following means.

Steps should be taken to ensure that the metal charge is admitted more quickly to all portions of the cavity formation, before certain remote, or restricted portions have solidified. This may be accomplished in several practical ways, which include: increasing the capacity of the gate to allow more rapid filling; shortening the runner channels, or re-shaping them to reduce the frictional resistance offered to the passage of the flowing charge; increasing the injection pressure; employing suitable overflow wells at selected points near critical regions in the die cavity, so producing better flow; increasing the heat of the die and the alloy charge; creating a more uniform distribution of heat over vital

areas of the die, by improving or even re-designing the layout and capacity of the water-cooling provisions.

In cases where the casting has to be gated and fed into a very thin wall section, from which the metal has to flow to much heavier sections, it is often helpful to provide longitudinal rib channels in the die, on the inside of the casting, to improve flow and to avoid premature solidification at certain points.

Sometimes the use of large size inserts having an extensive surface area may present difficulties, by seriously chilling adjacent portions of the flow before the remainder of the cavity has been filled, thus creating a cold shut. Any factor causing over-rapid chilling of the metal in the cavity should be eliminated.

Conclusion

The foregoing is by no means an exhaustive list of all the faults encountered in die cast components. It does include, however, some of the most commonly encountered ones. To a considerable extent the causes and cures of the faults noted in connection with the earlier descriptions are applicable to many of the other faults which cannot be referred to here owing to limitations of space. Some of the faults mentioned are also more specifically associated with certain types of casting alloy. For example, pinhole porosity, cracking, etc., are, in the main, connected with the higher melting point alloys, though they apply to all classes of alloy.

It will also doubtless be appreciated, from the descriptions given, that the economic production of satisfactory pressure die castings largely depends on the accuracy and quality of the die, its design features, the design of the component and its suitability for the casting process, the kind of alloy used, the working temperatures employed with both die and alloy, the injection pressures available, the velocity of the injected charge, and the gating and feeding provisions incorporated in the die.

In general, all those features must be eliminated whose effect is to retard the flow of metal in the cavity, or to hasten its premature solidification, or to prevent the alloy from making intimate contact with the surfaces of the die cavity at the instant of injection.

The design features of the component itself may, of course, greatly determine the liability towards any of the above-mentioned undesirable operating conditions, and thus the most careful and expert attention should be devoted to the evolution of such component designs in the first instance. This can best be accomplished by seeking the expert advice of an experienced die caster.

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Institute of British Foundrymen—London Branch. "Any Questions"—G. C. Pierce in the Chair. Waldorf Hotel, London, W.C.2. 7-30 p.m.

West of Scotland Iron and Steel Institute. "Engineering Problems connected with the Installation and Commissioning of a Cross Country Mill," by DR. W. S. WALKER. Joint meeting with Engineers' Group, Iron and Steel Institute. 39, Elmbank Crescent, Glasgow. 6-45 p.m.

Controlled Air Ventilation

THE provision of proper air movement in a ventilated or air-conditioned space presents one of the most important problems encountered in the design of an air distribution system. The right amount of air, correctly supplied to the various spaces served by the system, will not ensure the success of an installation, unless accompanied by suitable distribution within the space or spaces receiving treatment. Complications also arise, in that each space must be considered on its own merits; the form of air movement supplied being governed by such factors as the vertical and horizontal dimensions of the space, its usage, etc. The air outlet grilles used must, therefore, for environmental comfort and/or process requirements, be capable of adjustment to secure zones of air movement concordant with all

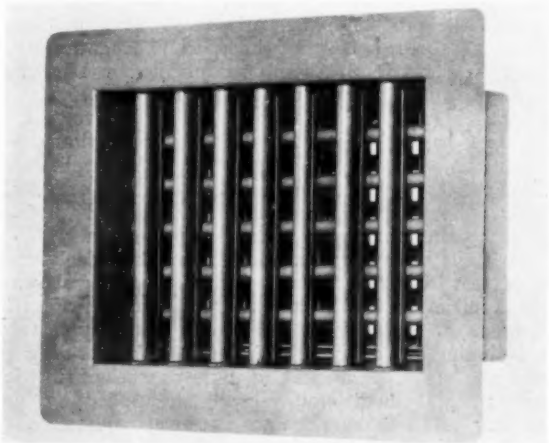

Fig. 1.—Face view of Deflecto Grille, showing arrangement of horizontal and vertical aerofoil blades.

operating conditions, and should, additionally, embody means for controlling the volume of air supplied.

Fig. 1 illustrates the Deflecto Grille, an air distribution device produced by Richard Crittall & Co., Ltd., of London, and employed extensively in all classes of buildings and factories, and on shipboard. The primary advantage of the grilles is that high air velocities are permissible without undue noise; this is made possible by the aerofoil design and efficient spacing of the two sets of grille blades. Furthermore, the air stream issuing at high velocity from a Deflecto Grille can be discharged or diffused in any direction or manner by adjusting the blades. The adjustment is made by hand or by the aid of a small key, and each blade can be adjusted independently to any desired angle; the setting of the horizontal blades giving the vertical diffusion of the air stream and the vertical blades the horizontal diffusion.

Intended for horizontal air discharge, or in certain cases, as in confined machinery spaces, hot spots in foundries etc., for setting at an angle, the Deflecto Grille operates satisfactorily at velocities in excess of 1,000 ft/min. for marine use, according to circumstances.

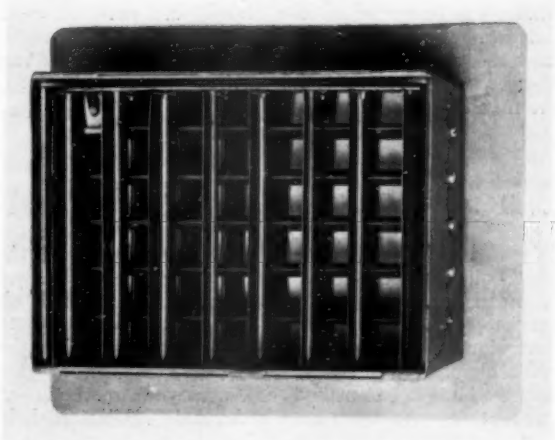

Fig. 2.—Rear view of grille, with opposed blade damper in partly closed position.

At these high velocities a large volume of air is delivered, resulting in one such grille performing the work of several ordinary grilles and, thus, requiring less duct-work and a correspondingly reduced initial installation cost. The zones of air movement secured are of varying widths, and lengths up to 80 ft. can be obtained, both of which are determined by the air velocity and the setting of the blades. Grilles are available in all sizes from 6 in. square upwards.

The value of these flexible units has been enhanced by the recent incorporation of a volume control, and this,

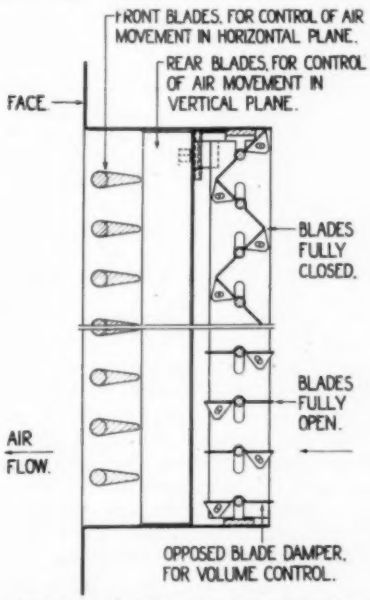
FRONT BLADES, FOR CONTROL OF AIR MOVEMENT IN HORIZONTAL PLANE.
REAR BLADES, FOR CONTROL OF AIR MOVEMENT IN VERTICAL PLANE.
FACE
BLADES FULLY CLOSED.
BLADES FULLY OPEN.
AIR FLOW.
OPPOSED BLADE DAMPER, FOR VOLUME CONTROL.

Fig. 3.—Diagrammatic horizontal cross-section of Deflecto Grille incorporating volume control showing: top, damper blades fully closed; bottom, open for maximum air flow.

as shown in Fig. 2 forms an integral part of the unit; the total depth of the grille together with opposed blade damper is under 4 in. Alternatively, the damper may be supplied separately with a 1½ in. frame, flanged if required, in any size, for use behind other types of grilles, and in ducts. An equal number of damper blades are embodied in the design, and each adjacent pair is, as will be seen from Fig. 3, arranged for opposed movement, so ensuring that the design features of the Deflecto Grille, i.e. even air distribution and direction, are maintained.

Setting of the damper is visible from the front of the grille. This operation is performed, also from the front, by means of a loose key, made detachable to prevent unauthorised persons tampering with the damper setting. Movement of the key actuates a cam mechanism designed to operate each pair of damper blades simultaneously and equally, from the complete shut-off to full output positions. At full output, i.e. when the blades are parallel with the sides of the grille, the frictional resistance of the grille is not increased by the damper blades.

The Protection of Ferrous Metals Against Corrosion

THE general aims of the Corrosion Group of the Society of Chemical Industry are (*a*) to afford a means of communication among chemists, metallurgists, engineers and others concerned with corrosion; (*b*) to stimulate interest in the need for the scientific study of corrosion; and (*c*) to encourage the application in industry of approved methods of prevention. At the Group's Annual Exhibition, held last month at Battersea Polytechnic, attention was focused on (*c*), the object of the Exhibition being to portray within a narrow compass some of the most important methods and processes for preventing the corrosion of iron and steel. For this purpose, the Organising Committee, with the assistance of a number of industrial firms and research laboratories, had assembled a collection of some thirty or forty exhibits.

Importance of Design

There is little doubt that much can be done to combat corrosion by suitable design of structures, particularly those intended for outdoor service, and a number of examples were shown, by means of photographs, of good and bad design. Whatever the design, there would, of course, be no corrosion if the structure did not come into contact with a corrosive medium, and whilst it is clearly difficult to operate large structures in such ideal conditions, there are instances where improvement of the environment can be effected: air conditioning can be used, for instance, in factories where bright steel parts, such as needles, etc., are made. There are also inhibitors which prevent or minimise corrosion by certain media. Added in small quantities to water, they can minimise its corrosive effects, whilst vapour phase inhibitors can be incorporated in wrapping paper to prevent corrosion of steel parts in storage or transit. These substances may also be used by enclosing them with the steel to be protected in a sealed polythene sheet container.

Corrosion is generally electrochemical in character, especially when steel is immersed in water or buried in soil. In such instances, the corrosion of the steel structure can be prevented by deliberately making it part of a corrosion cell, but so arranging matters that it is the non-corroded member or cathode of the cell. This technique has been used for some years in connection with buried pipelines, and has more recently been applied to the protection of ships' hulls.

Protective Coatings

Perhaps the most widely adopted method of rust prevention is by means of protective coatings, and a considerable number of exhibits related to this aspect of the problem. Whatever the final coating is to be the first step is the preparation of the surface to receive that coating. For the removal of mill scale and loose rust, the shot-blasting process finds considerable use, and an interesting exhibit in this section was a special "gun," which acts as a miniature shot blast cabinet and enables the process to be carried out on site. Other cleaning processes featured included phosphating as a basis for paint, and a combined pickling and priming technique particularly suitable for large steel plates. Paints constitute the most common protective coating for steel, particularly under atmospheric and immersed conditions, and besides the paints for general application, the exhibits included special anti-corrosive and anti-fouling compositions for ships' hulls, and modern silicone paints for high temperature protection.

Coatings of non-ferrous metals are also widely used to protect iron and steel, the exhibits displayed showing the application in various ways of metal coatings in common use. They included aluminium applied by hot-dipping and spraying; zinc applied by hot-dipping, spraying, sherardising, plating, and by means of zinc-rich paints and cementiferous zinc; tin applied by hot-dipping and plating; and two electroplated alloy coatings, tin-zinc and iron-zinc. The remaining exhibit in this group concerned the production of chromium coatings on steel by passing the vapour of a volatile chromium compound over steel heated to about 1,000°C. Other coatings displayed included a number of the "enveloping" type, such as vitreous enamel, bitumen, cement, and various plastics. For practical purposes, there is a need for temporary protective coatings which will keep steel unrusted in storage for an adequate length of time, and can then easily be removed to make way for the protective coating proper, and several of these were on show.

Corrosion Testing

In the successful development of protective coatings, industrial enterprise and scientific research go hand in hand, and the remaining section of the Exhibition illustrated experiments and tests in various scientific laboratories relating to the development of new protective measures and the assessment of their practical value. Of particular interest in this section was an exhibit showing a potentiostat being used to protect, by anodic polarisation, a pilot demonstration plant in 18 : 8 stainless steel, operating with a boiling 50% sulphuric acid solution. There are at present a number of limitations to this method of protection which are still being investigated.

of the part is still further reduced, and its corrosion resistance adversely affected. The latter effect gives rise to trouble in any subsequent electroplating of the casting. Of the three common forms of porosity, that caused by unequalised shrinkage is the most serious.

Shrinkage porosity most frequently occurs in those regions where there is a sudden change in wall thickness and metal mass, or, alternatively, where there is intense local overheating of the die cavity wall. When the alloy charge is injected into the relatively cool die cavity, a rapid decrease in volume occurs due to the normal shrinkage of the metal. If there is a lack of compensatory pressure feed from the flowing alloy at the gate or adjacent portions to accommodate for such volume contraction, metal has to be drawn from other portions of the casting which have not yet wholly solidified.

Normally, the tendency is for it to be drawn from the heavier and more massive sections, resulting in the creation of a void or porous spot in the internal structure. The high shrinkage and suction forces created by the contracting alloy draw metal from the inner layers of the wall, which are the last to solidify, and in this way the outer skin portions may appear perfectly formed, of the correct shape, and give an appearance of complete solidity to the casting.

The corrective treatment for this form of porosity may entail the relocation of the gating provisions to ensure adequate feed to those areas subject to the greatest amount of shrinkage. Alternatively by re-designing the die it is often possible to eliminate the regions of excessive shrinkage altogether. This may be accomplished by the use of ribs or small bosses, or by a general reduction of wall thickness. Similarly, the die may be vented in a more suitable manner, or may have its working temperature equalised by the more judicious use of the water-cooling provisions.

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Institution of Works Managers — Wolverhampton Branch. "The Manufacture of Ball and Roller Bearings," by R. E. W. SMITH. Star and Garter Royal Hotel, Wolverhampton. 7 p.m.

31st

Institute of British Foundrymen—London Branch. "Any Questions"—G. C. Pierce in the Chair. Waldorf Hotel, London, W.C.2. 7-30 p.m.

West of Scotland Iron and Steel Institute. "Engineering Problems connected with the Installation and Commissioning of a Cross Country Mill," by DR. W. S. WALKER. Joint meeting with Engineers' Group, Iron and Steel Institute. 39, Elmbank Crescent, Glasgow. 6-45 p.m.

Controlled Air Ventilation

THE provision of proper air movement in a ventilated or air-conditioned space presents one of the most important problems encountered in the design of an air distribution system. The right amount of air, correctly supplied to the various spaces served by the system, will not ensure the success of an installation, unless accompanied by suitable distribution within the space or spaces receiving treatment. Complications also arise, in that each space must be considered on its own merits; the form of air movement supplied being governed by such factors as the vertical and horizontal dimensions of the space, its usage, etc. The air outlet grilles used must, therefore, for environmental comfort and/or process requirements, be capable of adjustment to secure zones of air movement concordant with all

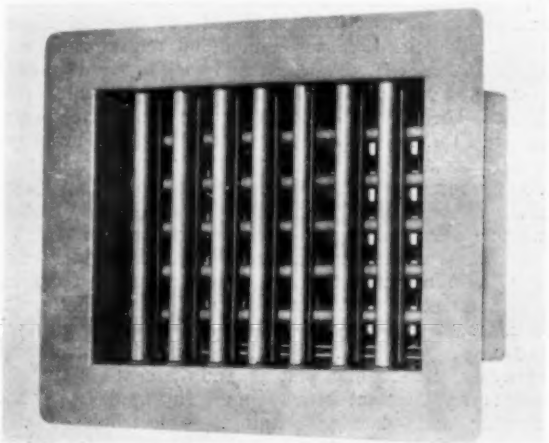


Fig. 1.—Face view of Deflecto Grille, showing arrangement of horizontal and vertical aerofoil blades.

operating conditions, and should, additionally, embody means for controlling the volume of air supplied.

Fig. 1 illustrates the Deflecto Grille, an air distribution device produced by Richard Crittall & Co., Ltd., of London, and employed extensively in all classes of buildings and factories, and on shipboard. The primary advantage of the grilles is that high air velocities are permissible without undue noise; this is made possible by the aerofoil design and efficient spacing of the two sets of grille blades. Furthermore, the air stream issuing at high velocity from a Deflecto Grille can be discharged or diffused in any direction or manner by adjusting the blades. The adjustment is made by hand or by the aid of a small key, and each blade can be adjusted independently to any desired angle; the setting of the horizontal blades giving the vertical diffusion of the air stream and the vertical blades the horizontal diffusion.

Intended for horizontal air discharge, or in certain cases, as in confined machinery spaces, hot spots in foundries etc., for setting at an angle, the Deflecto Grille operates satisfactorily at velocities in excess of 1,000 ft/min. for marine use, according to circumstances.

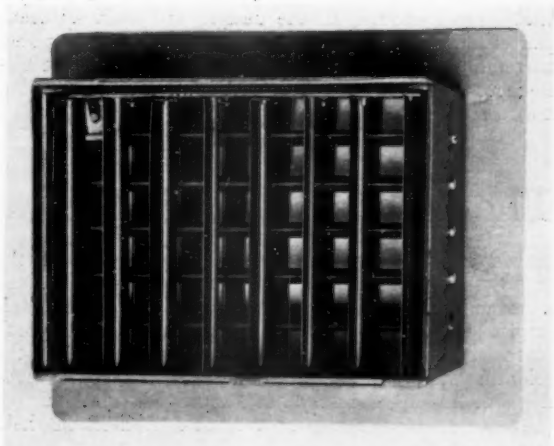


Fig. 2.—Rear view of grille, with opposed blade damper in partly closed position.

At these high velocities a large volume of air is delivered, resulting in one such grille performing the work of several ordinary grilles and, thus, requiring less duct-work and a correspondingly reduced initial installation cost. The zones of air movement secured are of varying widths, and lengths up to 80 ft. can be obtained, both of which are determined by the air velocity and the setting of the blades. Grilles are available in all sizes from 6 in. square upwards.

The value of these flexible units has been enhanced by the recent incorporation of a volume control, and this,

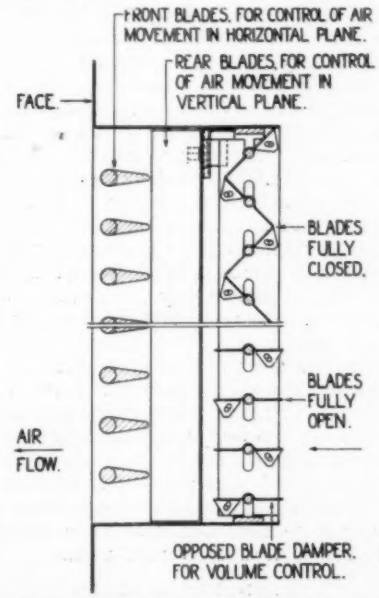

FRONT BLADES, FOR CONTROL OF AIR MOVEMENT IN HORIZONTAL PLANE.
REAR BLADES, FOR CONTROL OF AIR MOVEMENT IN VERTICAL PLANE.
FACE
BLADES FULLY CLOSED.
BLADES FULLY OPEN.
AIR FLOW.
OPPOSED BLADE DAMPER, FOR VOLUME CONTROL.

Fig. 3.—Diagrammatic horizontal cross-section of Deflecto Grille incorporating volume control showing: top, damper blades fully closed; bottom, open for maximum air flow.

as shown in Fig. 2 forms an integral part of the unit; the total depth of the grille together with opposed blade damper is under 4 in. Alternatively, the damper may be supplied separately with a 1½ in. frame, flanged if required, in any size, for use behind other types of grilles, and in ducts. An equal number of damper blades are embodied in the design, and each adjacent pair is, as will be seen from Fig. 3, arranged for opposed movement, so ensuring that the design features of the Deflecto Grille, i.e. even air distribution and direction, are maintained.

Setting of the damper is visible from the front of the grille. This operation is performed, also from the front, by means of a loose key, made detachable to prevent unauthorised persons tampering with the damper setting. Movement of the key actuates a cam mechanism designed to operate each pair of damper blades simultaneously and equally, from the complete shut-off to full output positions. At full output, i.e. when the blades are parallel with the sides of the grille, the frictional resistance of the grille is not increased by the damper blades.

The Protection of Ferrous Metals Against Corrosion

THE general aims of the Corrosion Group of the Society of Chemical Industry are (*a*) to afford a means of communication among chemists, metallurgists, engineers and others concerned with corrosion; (*b*) to stimulate interest in the need for the scientific study of corrosion; and (*c*) to encourage the application in industry of approved methods of prevention. At the Group's Annual Exhibition, held last month at Battersea Polytechnic, attention was focused on (*c*), the object of the Exhibition being to portray within a narrow compass some of the most important methods and processes for preventing the corrosion of iron and steel. For this purpose, the Organising Committee, with the assistance of a number of industrial firms and research laboratories, had assembled a collection of some thirty or forty exhibits.

Importance of Design

There is little doubt that much can be done to combat corrosion by suitable design of structures, particularly those intended for outdoor service, and a number of examples were shown, by means of photographs, of good and bad design. Whatever the design, there would, of course, be no corrosion if the structure did not come into contact with a corrosive medium, and whilst it is clearly difficult to operate large structures in such ideal conditions, there are instances where improvement of the environment can be effected: air conditioning can be used, for instance, in factories where bright steel parts, such as needles, etc., are made. There are also inhibitors which prevent or minimise corrosion by certain media. Added in small quantities to water, they can minimise its corrosive effects, whilst vapour phase inhibitors can be incorporated in wrapping paper to prevent corrosion of steel parts in storage or transit. These substances may also be used by enclosing them with the steel to be protected in a sealed polythene sheet container.

Corrosion is generally electrochemical in character, especially when steel is immersed in water or buried in soil. In such instances, the corrosion of the steel structure can be prevented by deliberately making it part of a corrosion cell, but so arranging matters that it is the non-corroded member or cathode of the cell. This technique has been used for some years in connection with buried pipelines, and has more recently been applied to the protection of ships' hulls.

Protective Coatings

Perhaps the most widely adopted method of rust prevention is by means of protective coatings, and a considerable number of exhibits related to this aspect of the problem. Whatever the final coating is to be the first step is the preparation of the surface to receive that coating. For the removal of mill scale and loose rust, the shot-blasting process finds considerable use, and an interesting exhibit in this section was a special "gun," which acts as a miniature shot blast cabinet and enables the process to be carried out on site. Other cleaning processes featured included phosphating as a basis for paint, and a combined pickling and priming technique particularly suitable for large steel plates. Paints constitute the most common protective coating for steel, particularly under atmospheric and immersed conditions, and besides the paints for general application, the exhibits included special anti-corrosive and anti-fouling compositions for ships' hulls, and modern silicone paints for high temperature protection.

Coatings of non-ferrous metals are also widely used to protect iron and steel, the exhibits displayed showing the application in various ways of metal coatings in common use. They included aluminium applied by hot-dipping and spraying; zinc applied by hot-dipping, spraying, sherardising, plating, and by means of zinc-rich paints and cementiferous zinc; tin applied by hot-dipping and plating; and two electroplated alloy coatings, tin-zinc and iron-zinc. The remaining exhibit in this group concerned the production of chromium coatings on steel by passing the vapour of a volatile chromium compound over steel heated to about 1,000°C. Other coatings displayed included a number of the "enveloping" type, such as vitreous enamel, bitumen, cement, and various plastics. For practical purposes, there is a need for temporary protective coatings which will keep steel unrusted in storage for an adequate length of time, and can then easily be removed to make way for the protective coating proper, and several of these were on show.

Corrosion Testing

In the successful development of protective coatings, industrial enterprise and scientific research go hand in hand, and the remaining section of the Exhibition illustrated experiments and tests in various scientific laboratories relating to the development of new protective measures and the assessment of their practical value. Of particular interest in this section was an exhibit showing a potentiostat being used to protect, by anodic polarisation, a pilot demonstration plant in 18 : 8 stainless steel, operating with a boiling 50% sulphuric acid solution. There are at present a number of limitations to this method of protection which are still being investigated.

Aluminium in the Food and Chemical Industries

By R. W. Nuttall, M.A.

Sales Development Division, Northern Aluminium Co., Ltd.

The use of aluminium in the food and chemical industries, whether as foil for packaging or heavier material for plant construction, has increased considerably in recent years. Although corrosion resistance is probably the major factor governing its choice, other characteristics of the metal are not without influence. A study of these properties is followed by a discussion of applications in this field.

ANY survey of this type must necessarily be of a general nature, and can only give an outline of the many applications for which light alloys have already been used in the food and chemical industries. Aluminium offers the principal advantage over steel of good resistance to corrosion, particularly in acid environments. In addition, it is lighter for the same strength, and has much higher thermal and electrical conductivities. Where other metals are considered, it has the further advantages of comparatively low cost and non-toxicity of the parent metal or any of its salts. It is intended here to enlarge on these properties and then show by examples how they can be put to profitable use.

Fig. 1.—Fish kits and loading trunks made by Pressoturn Ltd., in Noral M57S alloy.

Alloys Used

A factor that, probably more than any other, has extended the use of aluminium throughout almost every industry is the wide range of alloys, tempers and forms in which it is offered, each alloy having a distinctive combination of properties, while sharing such notable characteristics as lightness and good thermal conductivity. Aluminium of a purity of 99·5% and over (often called "high purity") is widely used for food and chemical plant, chiefly on account of the excellent corrosion resistance it possesses, for, broadly speaking, the purer the aluminium the greater the resistance to attack. Where greater strength is required, however, there are alloys which may be obtained in wrought or cast form. The commercially pure metal, which is of at least 99% purity and conforms to Specification B.S.1470/S1C in sheet form, is commonly used for hollow-ware, into which it can readily be pressed, drawn or spun, and for which it has adequate strength. It is supplied also as tube, sections and forgings. Where slightly greater strength and rigidity are required, an alloy containing about 1¼% manganese (B.S.1470/NS3) is used, being almost as easy to form and as resistant to corrosion. Much higher strength is possessed by an aluminium-magnesium-manganese alloy (B.S.1470/NS4) obtainable in sheet and extruded forms, which is fairly easily formed and possesses a high resistance to corrosive attack, especially in saline atmospheres. An excellent example of the use of this alloy is illustrated in Fig. 1. These fish kits, which are essentially two deep-drawn shells riveted together, are not only more hygienic than the usual wooden boxes and wicker baskets, but last immeasurably longer.

All the alloys mentioned so far are of the type that develop their strength entirely through work hardening. The heat-treatable alloys are, as a general rule, less corrosion resistant, but in certain alloys of this type resistance to attack is very high. Among such alloys, those that are commonly used in chemical plant have magnesium and silicon as chief alloying constituents. The medium-strength alloys, conforming to B.S.1476/HE9 and HE10, are each produced as tube or sections and are those commonly used for structural work; an alloy in the same group, Noral 65S, is obtainable in the form of sheet or extrusions. All these alloys are characterised by good corrosion resistance, with which Noral 65S combines very good forming properties. On account of its resistance to the attack of mine waters, which rapidly destroy ferrous metals, Noral 65S is recommended and widely adopted for use underground in British collieries. The capacity of the other two structural alloys, Noral 50S (HE9) and Noral 51S (HE10), to withstand many different types of corrosive atmosphere has been well proved in actual practice. For example, an open-sided roof built of Noral 51S (HE10) sections and Noral 3S (NS3) corrugated sheet, was erected over oxide purifiers at Sevenoaks, Kent, Gas Works and left unpainted (Fig. 2). Specimens removed for examination

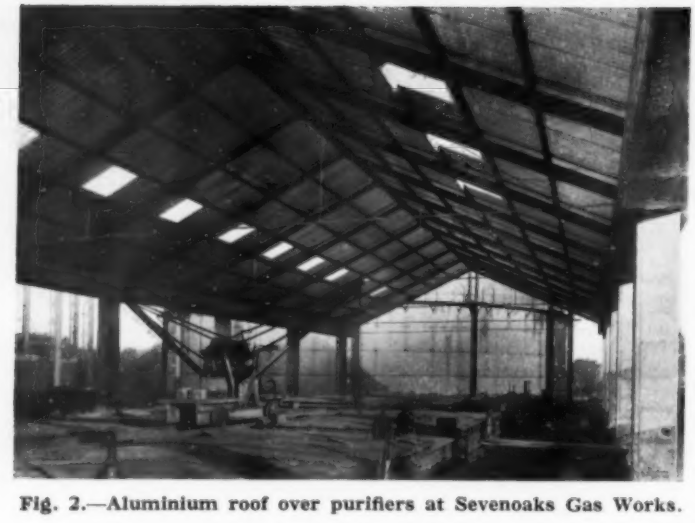


Fig. 2.—Aluminium roof over purifiers at Sevenoaks Gas Works.

after five years were found to be only slightly pitted, to a depth insufficient to affect the strength appreciably. This was proved by tensile testing, the results obtained being still in excess of the minimum figures called for in the respective specifications. In contrast, fittings of painted and galvanized steel which were also used showed quite severe corrosion. It is estimated that the roof will last for at least 25 years, which is impressive for a structure permanently subjected to a sulphurous atmosphere.

Among the casting alloys used in chemical equipment, one of the commonest is that conforming to B.S.1490/LM6, containing 12% silicon. In addition to its high corrosion resistance, it has excellent foundry characteristics, which enable it to be cast into intricate pressure-tight components. Beer-barrels are being die-cast (as two shells) in an alloy conforming to this specification. Of the range of heat-treatable casting alloys, Noral B116 (containing 4% silicon and ½% magnesium) is representative of a group that combines the notable advantage of taking and keeping a high polish with good corrosion resistance and good casting properties, all of which recommend it for food manufacturing equipment. A casting alloy containing 5% silicon and additions of copper and magnesium (LM16) can be cast into intricate shapes that retain their strength well at temperatures higher than normal. One of the strongest of the casting alloys, containing 10% magnesium (LM10), has also exceptionally high corrosion resistance, especially in salt atmospheres.

Corrosion Resistance

To emphasise corrosion resistance, as in the previous paragraphs, is to underline the importance of this characteristic in materials used in contact with food and chemicals. The bases for the claims made in respect of the various alloys are actual performance in service and the exposure of experimental panels to various atmospheres.

As is well known, aluminium corrodes only if there is a breakdown of the protective oxide film that is formed spontaneously on its surface. When corrosion does occur, it takes several different forms, which may exist simultaneously.

Uniform attack of the surface, equivalent to an overall etch, is caused by the dissolution of the oxide film, usually in strongly acid or alkaline conditions. As the rate of corrosion is regular, the life of the equipment may be predicted. Temperatures higher than normal tend to increase the solubility of the oxide film and, in effect, expose the metal to a wider range of corrosive media.

A less predictable type of corrosion is pitting, which occurs at isolated points and, therefore, tends to be more severe locally although it has less effect on the properties of the metal. The progress of pitting may be rapid at first, but it rapidly decreases and, generally speaking, the condition of the metal after ten years' exposure to conditions that cause pitting will be very little worse than after the first two or three years. Fig. 3 shows this effect graphically, and the shape of the curve has been confirmed by research experiments and practical applications extending back for nearly 50 years.

The most frequent cause of serious corrosion is contact with other more noble metals in the presence of an electrolyte. This is known as galvanic or electrochemical attack, and can be eliminated by suitable design methods. These include the substitution of aluminium for the other metal component, and the use of insulating materials (such as Tufnol) for ferrules and washers on bolts. In the case of steel, a strip of fabric impregnated with zinc chromate and inserted between faying surfaces is quite adequate. For copper, insulation must be more efficient, and even then trouble is sometimes experienced due to copper salts in solution or particles of the metal in suspension being deposited on the aluminium surface. If this is the case, prevention of corrosion proves more difficult, but periodic cleaning is the best method.

Another point to remember is that corrosion cannot take place at ordinary temperatures in the absence of moisture, and if a metal, and especially a bimetallic joint, can be kept dry it will not corrode.

In general, it may be said that the alloys mentioned above have excellent corrosion resistance, but some of the high strength heat-treatable alloys in the aluminium-copper and aluminium-zinc series do not behave so well and should not be used without adequate protection in most environments.

The correct choice of alloy is, therefore, of great importance in designing trouble-free equipment for the food and chemical industries. In the foregoing paragraphs, reference to the corrosion resistance of aluminium has been made on the assumption that the metal is unprotected by anything but its own natural layer of

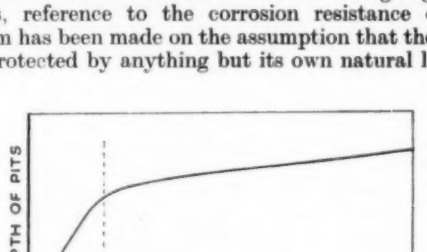


Fig. 3.—Curve showing depth of pitting against time for aluminium alloys.

oxide. When greater protection is found to be necessary, recourse can be made to various surface treatments which prolong the life of the metal in severe conditions. Thickening the oxide film by the electrolytic process of anodising is one of the best-known and most effective treatments. Electroplating with nickel, chromium, zinc or cadmium is also carried out, and there are many chemical treatments (the Erftwerke, for example) by which very thin films can be produced rapidly and cheaply, and which give aluminium extra protection in certain aggressive environments.

To combine the high corrosion resistance of the pure metal with the strength of the heat-treatable sheet alloys, the latter are sometimes clad with aluminium of high purity; usually the cladding is on both sides of the sheet but the blanks from which a certain type of beer barrel is being made are clad only on the side which will become the inside of the barrel. Aluminium food cans, like those of tinplate, are usually lacquered inside to prevent corrosion by the contents. Lacquers, paints and varnishes can, of course, also be used to protect aluminium when exposed to aggressive fumes, but such protection is unusual, and is only undertaken when conditions are exceptionally severe.

Other Characteristics

Aluminium's best-known and generally most important characteristic, lightness, tends to be overshadowed by others in discussing the advantages of aluminium food and chemical equipment; yet it is very important in many such applications. The great advantages of reducing the weight of containers that are moved by hand, rail or road are obvious; they are demonstrated in reduced labour and transport costs, and, often, in greater speed of handling. Less well-known are those applications in which a great reduction in inertia made possible by aluminium equipment increases immeasurably the efficiency of a chemical manufacturing process. An interesting example is the spin pot forged to several designs in Noral 51S alloy (Fig. 4). In service, these pots are revolved at some 8,000 r.p.m. while a cellulose thread, emerging from a bath of sulphuric acid, is spun on to them. It will be seen, therefore, that in this application lightness is as important as resistance to chemical attack. Originally, commercially pure aluminium was used, but it was later replaced by the present alloy, which is much stronger without being less resistant to attack by the cellulose.

The high thermal conductivity of aluminium—from four to five times that of mild steel and about half that of copper—is of particular importance in the chemical industry, where efficient heat transfer and effective heat distribution are essential to the working of many processes: aluminium is often used in heat exchangers, for instance. The good thermal conductivity of aluminium vessels is similarly advantageous in food processing—and in domestic cooking—where speed of working and heat economy are fully appreciated.

The distinctive brightness of aluminium, to which it owes the pleasant appearance of cleanliness that is particularly desirable in the food industry, is also important for other reasons. As aluminium has an extremely high optical and thermal reflectivity, it absorbs the sun's heat to a less degree than most other metals, thus keeping storage tanks made from it very much cooler and minimising evaporation of the contents. A measure of aluminium's high reflectivity, and, incidentally, its resistance to salt-laden atmospheres, is its extensive use for the reflectors of warships' searchlights. Aluminium is also a poor radiator of heat, and the temperature loss of hot liquids stored or processed in aluminium equipment is, therefore, comparatively small; moreover, foil is very often used to insulate chemical plant and the buildings housing it. The foil is wrapped in layers round the equipment, leaving small air spaces (which act as barriers to the heat) between each layer. As aluminium paint shares, to a high degree, the reflective and emissive properties of the metal itself, it is very often applied to industrial plant where such properties, and the paint's good appearance, are an advantage. Its excellent reflectivity is capitalised in such diverse installations as oil refineries, synthetic rubber plants and gas works; and on the hot surfaces of ovens and boiler room equipment, heat-resisting paints pigmented with aluminium are generally applied in the interests of thermal efficiency.

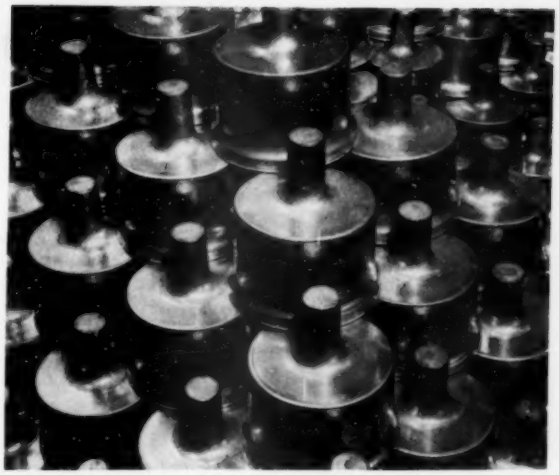


Fig. 4.—Spin pot forgings fabricated in Noral 51S alloy, for British Enka, Ltd.

Of particular importance to the food and pharmaceutical industries is the fact that the chemical compounds formed with aluminium are colourless, non-toxic and non-oxidising. Almost equally important in the manufacturing processes of those industries is the ease with which the metal can be thoroughly cleaned.

Ease of cleaning is usually less critical in other branches of the chemical industry, but is, nevertheless, of considerable importance, and a major factor influencing the ease of upkeep of aluminium equipment. Provided a suitable alloy is chosen for the work in hand, very little labour is required to maintain it in good condition. Painting or similar surface treatment, which is needed regularly by many other metals, is unusual with aluminium, its oxide skin offering both protection and pleasing appearance. Soap and water readily remove accumulations of dust and dirt, and organic solvents such as benzene, paraffin and trichlorethylene are useful in getting rid of grease and wax residues. Scales that cannot be removed by either of these methods often respond quickly to inhibited hydrochloric acid solutions. Alkaline cleaners are also useful, provided they are inhibited with sodium chromate or sodium metasilicate. For removing some residues, an abrasive may be necessary; in such cases gentle rubbing with steel wool, applied with soap and water, may be the answer.

Aluminium and its alloys are obtainable in many forms, and are readily fabricated by all the usual methods. Sheet products offered by the principal suppliers of the metal include not only flat and coiled sheet of high quality, rolled to a degree of dimensional accuracy that meets the exacting demands of the aircraft industry, but also foil stock and " circles " (or blanks)—of a size and shape suitable for pressing, drawing or spinning into hollow-ware—and " slugs " or " dumps " —also in a variety of sizes and shapes—which are impact-extruded into collapsible tubes and other small, narrow containers. The casting alloys can be given strong intricate pressure-tight shapes by sand, or die-casting, and for stronger components forgings are offered. Aluminium can readily be extruded into intricate sections that cannot be produced by any other method, or in any other material, and into tube which can be drawn if required.

Aluminium can be joined by all the common methods of riveting, bolting, welding and brazing. To avoid risk of galvanic corrosion it is good practice to use rivets of aluminium, which can be driven cold, with the exception of the larger sizes in some heat-treatable alloys. Aluminium bolts are to be preferred to steel ones, which need to be galvanised, sherardised, cadmium plated or coated with an inhibitive paint. Torch welding by oxy-acetylene flame is commonly practised, using flux (because of the immediate re-formation of the oxide film) and an aluminium-5% silicon alloy filler. Resistance welding—including spot, seam and butt welding—is also practised. The more recently developed process of argon-arc welding is a significant step forward in joining aluminium : by shrouding the weld pool with the inert gas, argon, the weld metal is prevented from re-oxidising after the skin has been broken up by the electric current. The joints formed by this method have mechanical properties at least as good as those of the annealed parent metal. The effectiveness of such methods of joining has increased aluminium's suitability for tanks, vats and the linings of containers.

FOOD INDUSTRY APPLICATIONS

Any review of the applications of aluminium in food processing should begin at home, where the widespread use of the metal, usually of commercial purity, is now commonplace in kitchen-ware of every description. An example of the use of a stronger alloy of the NS3 type is the pressure cooker, which benefits from the increased strength and rigidity, and is readily drawn in the heavy gauge usually required. Wrought cooking utensils have now very largely superseded those made from castings, but the latter are sometimes preferred, possibly for their greater strength, and are usually produced in the 12% silicon alloy conforming to LM6.

Fig. 5.—The contents of these aluminium cans were in perfect condition after 16 years.

Food Processing

In food processing on an industrial scale, aluminium is now much in evidence, the success of applications introduced many years ago continuing to build up increasing confidence in the material. There are examples of steam-jacketed boiling pans, for cooked meat and fish products, still in use after 30 years' service. Made of aluminium of 99% purity, and pressure tested at 40 lb./sq. in., they are considered more satisfactory than any other type. Similarly, an aluminium bun-proving cabinet, examined after some 25 years' service, was seen to have a long life ahead of it. It stands in the humid atmosphere of the bakehouse, and in use it reaches an average temperature of 100° F., becoming filled with steam as the dough rises : these are conditions normally unfavourable to metallic construction, yet the inaccessible parts of the interior showed nothing more than a superficial white corrosion deposit, while the exterior, and parts of the interior that could be cleaned periodically, were quite smooth and clean. These applications are representative of many increasingly found in bakery, confectionery and preserve manufacture. Apart from the long service they give, there is confidence in the hygienic properties of the metal, and, not least, appreciation of its lightness in trays, bowls and boxes, which would weigh up to twice as much in steel.

Wide use of the metal is evident also in the processing of meat, fish and gelatine, the canning and bottling of fruits and fruit juices and the preparation of fats, edible oils and some vinegars. Aluminium is one of the few metals that can confidently be used in the production of gelatine. In equipment for the processing and handling of fruits it needs no protection, but anodising or similar treatment is necessary for storage or canning. Fruit juices, which contain protective colloids, have less action than the fruit acids on aluminium : fats and edible oils are unaffected by the metal and their flavour is not impaired. For use in processing certain fats, such as margarine, the aluminium is more satisfactory if anodised.

Food Packaging

The preserving of foodstuffs in aluminium cans is much more widely practised on the Continent and in North America than in Britain, one of the chief reasons being the exceptionally low home price of British steel, which puts aluminium at a serious disadvantage in competing with tinplate. It is felt by some British experts, however, that aluminium's capacity for maintaining perfectly the original flavour of the foodstuff will eventually be widely recognised to its advantage. In Scandinavia, for example, where aluminium is cheaper than tinplate, twenty-five years' experience of canning several types of fish—sardines, herring fillets, etc., mostly in oil—has been very successful (Fig. 5). An improved method of canning fish, recently developed in Norway, makes use of a special anodising process which incorporates sealing the anodic film with lacquer on the

inside of the can. A magnesium-silicon alloy is used, which is stronger than the commercially pure metal and can be rolled as cheaply.

An innovation that is proving popular in Germany is the sale of beer in aluminium cans produced by impact-extrusion. Unlike the usual glass bottles, they are non-returnable and cost slightly more, but they are attractive enough to find numerous end-uses once their contents have been consumed. Work is proceeding on the development of a flat-topped can formed from sheet, which would be cheaper, as it would use less metal; moreover, as the duty on alcohol imported into some countries is based on gross weight, the already great advantage gained from the use of aluminium would be increased. On the Continent, and to a less extent in Britain, impact-extruded containers are used also for edible creams, mustard, jams and butter, the aluminium used being of commercial purity.

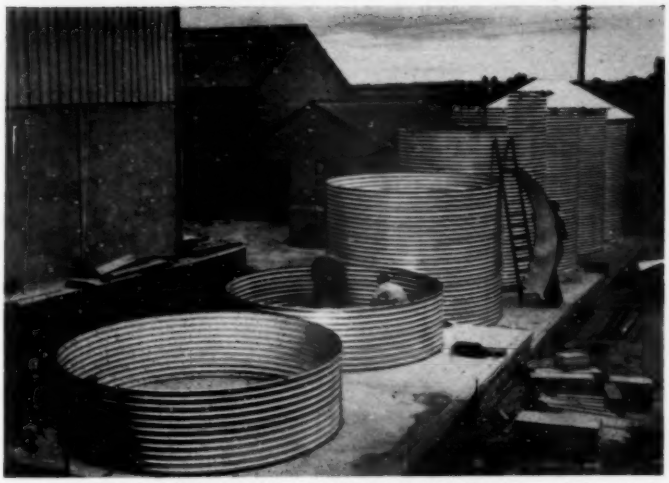


Fig. 6.—Battery of grain silos made by Fredk. Braby and Co., Ltd., in Noral 3S alloy corrugated sheet.

An alloy of the NS3 type has been found to satisfy best the very great demand for aluminium closures used to seal jars and bottles of foodstuffs. Within the last few years, aluminium has been found ideal for " pilfer-proof " seals such as are used on bottles containing fruit squashes; they are easily broken by sharply turning with the fingers and clearly show whether the contents have been tampered with.

The growing use of aluminium foil for wrapping foodstuffs, sweets and other confections is well known because it is in everyday experience. In Britain it is not yet as easy for the housewife to buy rolls of foil for domestic use as greaseproof paper, but foil can be purchased at many stores and may well become as indispensable to the British kitchen as it appears to be to the American, where it is acknowledged to be the best wrapping material for keeping food fresh. Mention must also be made of the use of aluminium foil for milk bottle caps: it has been reported that about 5,000 tons a year are being used for this purpose in Britain alone, and that in Scandinavia, Holland and Switzerland more than 90% of the milk bottles in use are sealed with aluminium caps. A notable feature of the aluminium cap is that, unlike the cardboard disc commonly used in Britain, it fits well down over the pouring rim, and therefore satisfies the clause in the Dairy Act, which comes into force this year, stipulating that all milk bottles must be sealed by a cap that completely covers the rim. In Switzerland, heat-sealed foil packs have made their appearance, in which the foil is laminated with a plastic film.

Dairying

To do justice to aluminium's position in the most important food-producing industry—farming—would itself require a lengthy article, for the term " farming " includes countless activities, widely different in character, and aluminium has its use in almost every one of them: from the cultivation of the soil to the storage of the crop (Fig. 6)—or from the incubation of the egg to the housing of the fowl; the metal is used in all its forms and advantage is taken of all its characteristics. To avoid giving a long list of applications reference will be made only to one branch of farming—dairying.

Switzerland and Denmark, the two major dairy-farming countries of the world, have been using aluminium dairy equipment for some twenty years, in milk churns, pails, storage tanks, road tankers, pasteurising and cheese-making plant, and other processing equipment. In Britain, also, certain types of aluminium dairy equipment have been in use for twenty years and more. Some of the earliest aluminium milking machines produced in Britain date from about 1928, and many of their original components are still in service. Aluminium is used chiefly in the bucket-type and the portable milking machines, in the pail, the lid and pulsating mechanism and the teat-cup shells. By using aluminium in the pump and the engine, as well as in the milking unit, the complete set of portable equipment can be propelled by one man. To cool the milk as rapidly as possible, several types of cooling device have been produced; they consist essentially of a simple turbine—an aluminium casting—which fits over the mouth of the churn and is rotated by a stream of water which is then sprayed over the outside walls; an agitator—of aluminium tubing—inside the churn is revolved by the same means.

In the process of pasteurising by the " high temperature-short time " method, which is used for most of the milk consumed in Britain's towns and cities, the milk is raised to a high temperature by passing it through a heat exchanger. In such equipment, aluminium's lightness is as advantageous as its high thermal conductivity, for the heat-exchange plates are bulky and need to be dismantled periodically for cleaning and sterilising. Recent developments in the pasteurisation of milk in bottles instead of in bulk have encountered the difficulty of bursting the closures and cracking the glass; the most effective answer may possibly be aluminium milk bottles, which have been successful on the Continent. In butter and cheese-making equipment, aluminium sheet of commercial purity is widely used, and cast aluminium churns have met with success. The combined use of castings and extrusions is seen in Fig. 7. Anodising the metal has been found effective in reducing the tendency of the butterfat to adhere to it.

In spite of the proven success of prototype aluminium milk churns in Britain, they are not yet used to anything like the same extent here as on the Continent; there are signs, however, that practical recognition of their advantages by the Government will not be long

Fig. 7.—Finishing aluminium alloy cheese vat stirring gear at the works of Fredk. Braby and Co., Ltd.

delayed. Such churns withstand excellently the rough treatment they get in service, and are perfectly hygienic, being very easy to clean. The chief disadvantage is the high initial cost—over half as much again as that of the tinned steel types—but this can be more than outweighed by the elimination of retinning costs, saving of deadweight and longer life. The capacity of an aluminium churn (which had already given 3½ years' service) to withstand repeated washing and sterilising equivalent to what it would receive over a 10-year period of use was demonstrated in a reeent test, from which the churn emerged in perfect condition.

Aluminium tankers for transporting milk by road have the considerable advantages that accrue from the increased payload, and they benefit also from the metal's reflective and heat-insulation properties. When aluminium foil is used as the insulating material—between the inner and outer shells of the tank—the saving in weight is even greater ; on a 2,000-gallon vehicle it may be equivalent to over 65 gallons of milk.

Brewing

From the dairy to the brewery may be a big step, but at least in the extensive use of aluminium these industries are similar. The brewer can have confidence in specifying aluminium for such equipment as fermenting tuns, storage vats, yeast tubs and coolers, for the taste, smell and colour of the beer are not affected by contact with the metal. Normally, aluminium of high or commercial purity is used, in wrought or cast forms, in either of which it can be kept perfectly clean and of good appearance. Where it is felt that stronger alloys are necessary, as in beer barrels, high corrosion resistance need not be sacrificed to strength if the surface in contact with the beer is clad with high-purity material during rolling.

Care in the design of aluminium brewing equipment, particularly with reference to drainage, drying, and methods of support, ensures that moisture traps are avoided, and is well repaid in long service. The proper care needed in cleaning the equipment can easily be taken ; inhibited alkaline or mildly acid cleaners are commonly used, though beer-stone needs to be attacked by some such mixture as kieselguhr, dextrine and 1% nitric acid—which is allowed to soften the encrustration for several hours—followed by thorough rinsing.

One of the most impressive installations of aluminium brewery equipment was carried out not long ago at the Dublin brewery of Arthur Guinness, Son & Co., Ltd. It includes several beer storage vats, each having a working capacity of 2,000 Imperial barrels ; they are fabricated from sheet of high purity, joined by welding, and, despite their size, have no internal struts, frame bars or stiffeners. The fabricators, The London Aluminium Co. Ltd., have also supplied fermenting tanks, of high-purity aluminium and 100 Imperial barrel capacity, to a brewery at Burton ; the metal, which is ¾ in. thick has been given a satin finish on its interior surfaces.

At a brewery of Ind Coope & Allsopp, Ltd., 1,100 sand castings in Noral 160 alloy are used in the pasteurising plant. They are the slats of a conveyor system which carries the bottled beer through the pasteurising chamber, where their advantages of lightness—they weigh only 14 lb. each—and corrosion resistance are important.

Flour Milling

A review of aluminium in the food industry would be incomplete without mention of the world's first all-metal flour mill installed last year at Driffield, Yorkshire, to be followed by similar installations at Manchester and elsewhere. Among the chief advantages of replacing the normal wooden construction with metal is the reduced fire risk ; further, the use of aluminium has generally enabled this change to be made while reducing the weight, yet ensuring great strength. In the variety of milling equipment specially re-designed for the new installation, aluminium was used as both sheet and extrusions.

CHEMICAL INDUSTRY APPLICATIONS

It is impossible in a short article to give a complete dictionary of the various chemicals and the reaction of aluminium to them ; it is also difficult to generalise about such reactions, for each of the alloys reacts differently. It might also be mentioned that the presence of certain minor impurities in a chemical normally harmless to aluminium may start corrosion. Examples taken from various industries may serve to illustrate what is known about the behaviour of light alloys and suggest other possible applications.

Paint and Varnish

In the paint and varnish industry, aluminium is itsel a major constituent in one range of products. Aluminium paints, with their impressive combination of excellent durability, reflectivity and hiding power are now widely accepted in Britain and countries overseas. They are pigmented either from powder or paste, the latter having sufficient advantages (including ease of mixing) to give considerable significance to the introduction of the first Alpaste plant into Britain, at Northern Aluminium Company's Banbury Works, in 1935 (see Fig. 8). The grades of Alpaste produced are suitable for general purpose paints and special paints for wood priming. underpainting on steel, alkali resistance, and heat resistance ; a fine grade is used also for silver printing ink.

As aluminium offers good resistance to varnish fumes, solvents, oils and pigments, it is often used in equipment for paint and varnish manufacture. Anodising is resorted to when greatly superior resistance is required, and strong alloys are used in such items as emulsifiers, hoppers and piping, when greater strength is necessary. Aluminium has little or no catalytic affect on the oxidation and polymerisation of oils, therefore its use is very successful in oil boiling and processing equipment, whether using open or closed pots. When aluminium materials are used, the absence of a catalytic drying effect reduces the trouble arising from skin formation on the surface of the varnish. Pots in which varnish is to be maintained at a high temperature are sometimes lined with foil. Among aluminium applications in varnish manufacture are included air-conditioning equipment, filter presses, heat exchangers and trays for the solidification of such products as ester-gum.

Fig. 8.—Aluminium-painted cyclones at Northern Aluminium's Alpaste plant.

Explosives

The manufacture of explosives is another industry in which aluminium powder is used in the product, being part of the charge for high explosive bombs and depth charges. On the other hand, the non-sparking properties of aluminium equipment are, paradoxically enough, of great advantage in handling and manufacturing explosives. The mixing, drying, evaporation and crystallisation of nitroglycerine and dynamite are all done in aluminium equipment, as are the evaporation and crystallisation of ammonium nitrate used in some explosives.

Soaps and Cosmetics

Soaps and cosmetics are made and stored in equipment of high-purity or commercial-purity aluminium, or, where greater strength is required, of the NS4 type of alloy. Even at boiling point, stearic, palmitic and oleic acids have little or no effect on these materials, which are used in sheet and extruded forms to make condensers and condenser coils, filter presses and drying vats, as well as storage tanks. The essential fats and oils of the soap and cosmetics industry are also stored and transported in aluminium equipment; glycerine and pharmaceutical products manufactured by acid or weakly alkaline processes are confidently produced and handled in aluminium.

Rubber

In the manufacture of rubber, aluminium and its alloys withstand attack under the variety of conditions encountered. Their good thermal conductivity is distinctly advantageous in the processes of dipping, curing and vulcanising; and they do not adhere to raw latex or vulcanised and hard rubber products, nor do they need the benefit of surface preparation to give the desired glossy finish to the products. For all these reasons, aluminium and its alloys are used throughout the whole process of manufacture, from the collection, storage and shipping of the latex and other raw materials to the fabrication of rubber products, including tyres and other moulded goods.

Paper

In the production of pulp and paper, certain of the fumes evolved and chemicals formed are highly corrosive to some metals, but not to aluminium. Sulphur dioxide, for example, does not corrode it, and sulphurous acid in low concentrations is not severely aggressive towards it. Among the equipment made of aluminium are ventilating ducts and hoods, screen covers, sector frames, pulp troughs and heat exchangers. Mention might also be made of the logging chutes and flumes, made of 65S alloy, which have the advantages of lightness and resistance to the combined erosive and corrosive effects of the water.

In the manufacture of cellophane " paper " by British Cellophane Ltd., Bridgwater, the conditions are exceptionally severe: in this process, viscose in alkaline solution is extruded into dilute sulphuric acid, after which the solution immediately gels and is then passed as a strip through various baths which wash and condition it. Fumes containing hydrogen sulphide, carbon disulphide and sulphuric acid are evolved, and are drawn off through an exhaust system in which sheet of various aluminium alloys is used. In spite of the very severe conditions, each of these materials has already given several years' service and is assured of giving more.

Textiles

Mention has already been made of an application of aluminium to the textile industry, but it is only one of many. The sulphide solutions and fumes of the viscose rayon process have little effect on the metal, and in this process also it is used for ducting and air-conditioning. The bleaching of textiles by hydrogen peroxide can confidently be effected in equipment made of high-purity aluminium, because the metal does not catalyse the decomposition of this chemical. In the dyeing of textiles in neutral and acid baths, aluminium is again suitable, though in the latter an inhibitor such as sodium dichromate or sodium silicate is used to protect the metal.

Sewage

In the disposal of domestic and industrial sewage, aluminium has also been used with success, for it resists attack by the sewage itself and the decomposition products of the sludges, including hydrogen sulphide, methane, carbon dioxide and nitrogen. Among the wrought alloys used, in addition to the commercially pure metal, are those of the NS3 and HE10 types.

Fig. 9.—A selection of aluminium boxes containing various products of the chemical and food industries.

Organic and Inorganic Chemicals

Of the great number of organic and inorganic chemicals manufactured, handled and stored in aluminium equipment, there is space to give only a very brief summary. They include the alcohols, some of which in aqueous solution tend to corrode the unprotected metal, but many of them are stored in aluminium containers, and some are processed in aluminium equipment. Saturated hydrocarbons do not attack aluminium, nor do unsaturated hydrocarbons, except at temperatures higher than normal and in the presence of a catalyst; they are, therefore, often stored in aluminium tanks. As the metal is highly resistant to fatty acids, its use in the manufacture of edible oils is an assurance against oxidation, rancidity and discoloration. Turpentine, camphor, eucalyptus oil, cinnamon oil and many other essential oils are handled in aluminium containers, as are esters and aldehydes. Formaldehyde, for example, is stored in tanks of capacity up to 15,000 Imperial gallons.

Among the inorganic chemicals, neutral solutions are less aggressive towards aluminium than those that are decidedly acid or alkaline. The *p*H values are often a useful guide in predicting the behaviour of the metal, but the nature of the ions in the solution is actually more important than acidity or alkalinity. As would be expected, aluminium resists oxidising substances better than reducing agents.

In general, acid solutions do not attack aluminium as rapidly as alkaline solutions, but strong acids themselves have a serious effect unless precautions are taken. For example, hydrochloric acid is corrosive in any concentration, but it is used in aluminium fermentation vats to remove " beer-stone," a scale which forms during fermentation, and the addition of dibenzyl sulphonic acid as an inhibitor protects the aluminium. Sulphuric acid is less corrosive towards aluminium, but in strengths up to about 80% the rate at which corrosion takes place is high, and increases with concentration; with fuming sulphuric acid, the metal is passivated and attack is not serious. Similarly, concentrated nitric acid only slightly attacks the metal; generally corrosion is slow with dilute and strong solutions, and is at its most severe in the range of 20–40% concentration. Rise in temperature increases attack considerably, and annealed metal is found to be more resistant than that in the fully-hard condition.

Most of the common organic acids, especially those present in fruits, do not attack aluminium at room temperatures, but hot solutions are liable to be corrosive. As is well-known, aluminium is extensively used in dairying; there is reason to believe that the non-acid constituents of cream tend to protect the metal, for it has much less effect than a plain 1% solution of lactic acid.

Acid salts usually react with aluminium to the same extent as their acids. Salts formed by a strong acid and a weak base—for example, aluminium nitrate and sulphate—are sometimes handled in aluminium equipment. Strong alkalis, generally, are found to be particularly corrosive, but mention should be made of the excellent service given by the metal in the construction of stills, fractionating columns and condensers for the recovery of by-product ammonia and other equipment used in manufacturing and handling ammonium compounds.

Petroleum Plant

Aluminium's resistance to ammonia, carbon dioxide, hydrocarbons, brine and sulphur compounds makes it an effective material for the construction of petroleum plant, and the metal's characteristics of lightness, high reflectivity, poor emissivity and low tendency to spark are among its other advantages in this field. In the refinery it is used as sheathing for insulated piping, fractionating columns and storage tanks; at Shell Haven on the Thames Estuary, aluminium sheathing still retained its original brightness after two years' service, during which period galvanised iron in the same installation had rusted and perforated in places. Heat exchangers having tubes, tube sheets and shell of aluminium capitalise the metal's good thermal conductivity, durability and (as aluminium tubes are less than one-third the price of those in Admiralty metal) its lower cost. Aluminium trays and bubble caps for fractionating columns have been successful in America: for instance, ten to fifteen years' service have been given by cast bubble caps in debutaniser columns handling petroleum distillate from West Texas sour crude oils at temperatures between 200° and 425° F. In America, also, aluminium roofs over tanks storing sour crude oils have been in use for twenty-five years, in conditions where steel roofs failed in less than five. As would be expected, aluminium tubing finds many applications in the industry; a notable example is the oil pipeline, extruded in Noral 50S alloy, installed on a jetty projecting into the Thames Estuary at Purfleet, Essex. Examined after five years, its condition was entirely satisfactory. These are only a few of many applications in which aluminium renders service to the petroleum industry; in a sister industry, namely the production of gas and its by-products, conditions are roughly the same and aluminium is proving similarly useful. To these and many other branches of the great chemical industry, and to the production and distribution of food, the aluminium industry is devoting considerable research which will doubtless extend the uses of the metal in the future.

Fork Lift Hire Fleet

GEORGE COHEN, SONS AND CO. LTD.—head of the " 600 " Group and already operators of Britain's largest contractors' plant hire fleet—are taking a hand in the fork lift truck hire business. To all firms faced with occasional handling problems they are offering the latest diesel model I.T.D. " Stacatruc," having a 2-ton 12-ft. lift.

Recent Developments in the Riveting of Aluminium

By A. W. Brace, A.I.M.
The Aluminium Development Association.

The last twelve months have seen the culmination of five years' work on the riveting of large aluminium structures which, in that time, has moved from laboratory experiment to full scale achievement. In this article, the author discusses the alloys suitable for use as rivets, and the design of preformed and driven heads, finally describing a number of recent applications of this method of joining.

RIVETING of steel has long been established, and the existence of tens of thousands of structures held together by this means testifies to its reliability. It is often said that riveting is being superseded by welding, and whilst on certain classes of work, particularly in shipbuilding, welding has technical and economic advantages, it is also not without its problems. On the other hand, riveting is particularly suited to the type of fabrication common to structural workshops, where widely spaced connections are common, and where it is rare for more than a few structures of any particular design to be required at any time. In fact, even on so-called " all-welded " structures, there is still quite a lot of riveting.

As a structural material, aluminium has advantages for applications such as crane jibs, certain types of bridges, mine cages, etc., where reduction of dead-weight or high resistance to corrosion is important. It already finds economic application in these fields, despite a rather high initial material cost. It is obvious that to build structures of this type, joining methods such as riveting and welding are necessary.

During the 1939–45 period, much experience was gained in riveting aluminium aircraft structures, using rivets up to about $\frac{1}{4}$ in. dia. In some small marine craft, rivets of $\frac{3}{8}$ in. or even $\frac{1}{2}$ in. dia. had been used, occasionally, as they had in specialised heavy transport vehicle bodies. The early post-war period saw the use of aluminium alloys in ships' superstructures, and rivets up to $\frac{5}{8}$ in. dia. were driven—but not without some difficulty. Up to this stage, all riveting had been by cold driving, and a technique rather similar to steel riveting was employed. It was concluded that if larger rivets were to be driven there would have to be developed a hot-riveting technique or some new method of carrying out riveting operations.

Need for Larger Rivets

When the Aluminium Development Association held a Symposium on Riveting in 1947, the position was reviewed and the need for larger rivets was indicated, possibly also in stronger alloys, if aluminium were to be used for large structures. A Technical Committee was set up by the Association, and in 1948 it was decided that rivets of up to $\frac{7}{8}$ in. dia. would be required for such work, with the possibility of the occasional use of 1 in. dia. rivets. It was decided to study riveting methods and a range of alloys, so that rivets up to $\frac{7}{8}$ in. dia. could be driven in suitable materials. Subsequent work, which has been a major contribution to the establishment of successful heavy riveting techniques in this country, has been carried out under the guidance of this committee.

TABLE I.—NOMINAL COMPOSITION AND MECHANICAL PROPERTIES OF ALUMINIUM ALLOYS SUITABLE FOR RIVETING.

Alloy (B.S. 1476)	Related Specifications	Nominal Composition			Minimum Mechanical Properties			Ultimate Shear Stress (typical) (tons/sq. in.)
		Mg (%)	Si (%)	Cu (%)	0·1% Proof Stress (tons/sq. in.)	Ultimate Tensile Strength (tons/sq. in.)	Elong. (%)	
N4-M	—	2·25	—	—	—	11	18	8
N5-M	—	3·5	—	—	6	14	18	10
N6-M	L58	5·0	—	—	7	16	18	11
H10-W	—	0·65	1·0	—	7	12	18	10
H10-WP	—	0·65	1·0	—	15	18	10	12
H12-T	L63	0·35	—	2·0	—	17	—	11
H14-T	3L37	0·65	(0·6 Mn)	4·25	15	25	15	17

Most aluminium alloys are suitable for riveting, but the stronger alloys are more attractive, since they enable high joint efficiencies to be achieved. Table I gives the main aluminium alloys investigated, with their nominal compositions and mechanical properties.

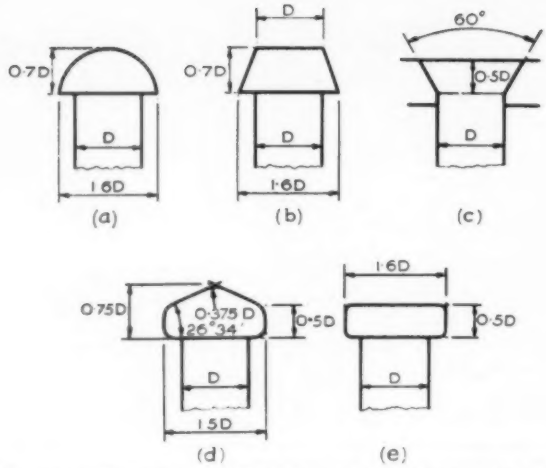
Of these alloys, the first three are of the non-heat-treatable type which can be hot driven within a fairly wide temperature range ; they all possess high corrosion resistance, especially in marine atmospheres. The remaining four materials are all heat-treatable, but can be more readily driven in the freshly-quenched condition. Under these conditions H10-WP alloy would not attain its full properties, as the rivets would be in the solution treated (W) condition, an elevated temperature treatment being necessary for ageing.

It is obvious that not only is a material expected to have good tensile and shear properties, but in the form of rivets it must be capable of being driven by normal riveting equipment. Early work by Bailey and Brace[1] was aimed at establishing the load required to squeeze-drive aluminium rivets with points* mainly of the type used on steel.

The dimensions of the shapes investigated are shown in Fig. 1. It was established that the Flat point was the easiest to drive, and that if the load required to close it were taken as unity, then that necessary for the other shapes could be calculated by means of the simple factors given in Table II.

Since a load of about 90 tons is required to close $\frac{7}{8}$ in. dia. Snap points in the common alloys, the advantages of using a Flat or N.A. Cone point are obvious.

* For convenience of reference the manufactured end of the undriven rivets will be referred to as the head and that formed in closing the rivet as the point.



(*a*) Snap ; (*b*) Pan ; (*c*) CSK 60° ; (*d*) N.A. Cone ; (*e*) Flat

Fig. 1.—Details of rivet points investigated.

Pneumatic hammer driving gave comparative results of a similar order, based on driving time, but it was difficult, with large cold-driven rivets, to obtain consistent Flat or Cone points of satisfactory shape and dimensions. The Pan point, although not the easiest to drive, was the most practicable with which to obtain consistent results.

Laboratory Tests on Alloys

At the same time, laboratory work was being carried out to evaluate the various aluminium alloys as rivet materials, by comparing, in particular, their compression properties with their riveting characteristics. It was established[2] that, provided the height/diameter (H/D) ratio was around 0·7–1·0, there was good correlation between the force required to produce a 60% increase in diameter of the compression specimen (more easily measured as a percentage decrease in height) and that required to form a Flat point of similar dimensions on a rivet.

Apart from the value of indicating the size of equipment necessary to handle rivets of any alloy or diameter, this test, sometimes referred to as the "dump" test, has some value as a quality control. It is generally accepted that the test will readily disclose any surface defects in the material, and also the presence of a layer of coarse grained material which sometimes occurs on the outer surface. In addition, it has been suggested

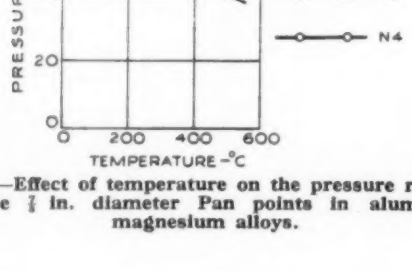


Fig. 2.—Effect of temperature on the pressure required to close ⅞ in. diameter Pan points in aluminium-magnesium alloys.

TABLE II.—LOAD FACTORS FOR FORMING VARIOUS RIVET POINT SHAPES.

Point Shape	Load Factor
Flat	1·0
N.A. Cone	1·1
Countersunk 60°	1·6
Pan	1·8
Snap	2·0

that if the material does not withstand expansion to 1·6 times the diameter of the original bar without shear cracks appearing, then it is unlikely to make satisfactory rivets.

Some doubts have been expressed as to whether this test should not be treated with reserve, or at least the maximum diameter lowered to 1·5*D*. It is pointed out that the sensitivity of head shapes to cracking varies in borderline cases. This requirement has, however, been written into B.S.1974 "Large Aluminium Rivets," pending the development of a more suitable test. The standard also makes provision for shear tests to be made on bar stock and rivets, with a view to obtaining data for specifying minimum shear values.

An interesting point brought out by this laboratory evaluation is that tensile properties give little indication of the behaviour of a rivet material; compression characteristics, on the other hand, provide a fairly reliable guide, since simple riveting operations approximate to compression. Heat-treatable alloy rivets in the freshly-quenched condition give the best combination of ease of driving for the shear strength developed by the maximum size of rivet which can be driven, followed by fully heat-treated (WP) material. Hot driving of the aluminium-magnesium alloys offers a gain similar to that obtained with freshly-quenched heat-treatable alloys. A practical illustration of this improvement is shown in Fig. 2, based on driving tests on rivets at room temperature and when heated to 250°, 400° and 500° C.

Practice in this country has tended to favour the use of N6 rivets, often delivered in the annealed condition. Up to ⅝ in. dia., they can be cold driven, but above this size hot driving is preferred. In the U.S.A., much use has been made of aluminium-magnesium-silicon rivets in a heat-treated alloy of the H10 type, but containing 1·0%Mg, 0·6%Si, 0·25%Cu and 0·25%Cr. In the construction of the liner *United States*, over a million rivets in this alloy were used[3]—mainly ⅜–⅝ in. dia. They were in the solution-treated condition when delivered, and were kept in refrigerated storage until required for use. In this country, some use has been made of H10-WP rivets (cold driven) for highly stressed connections, and tests on joints by Francis[11] indicated that it has given higher efficiencies than other rivet alloys (except H14). It is possible that, for special purposes, some use will be made in the future of H14 rivets, quenched and refrigerated until required for use. With proper technique, these rivets, which have a shear strength of 18 tons/sq. in. or more, can be driven with existing pneumatic hammers.

Hot Driving Aluminium Rivets

As indicated earlier, large aluminium rivets are not easily driven in the cold, but hot driving requires the availability of equipment which will ensure that the rivets are heated to the correct temperature. An electric furnace has been developed by the Aluminium Development Association in conjunction with R. M. Catterson Smith Ltd., Wembley[4], which it is believed meets the

requirements of shipyards and structural shops. It permits a high output of hot rivets and, by using a Sunvic Energy Regulator in conjunction with a pyrometer, ensures rivets being heated to 400°–500° C. This furnace is shown in Fig. 3.

Since aluminium rivets are usually produced by cold forging, it is obvious that, unless the quantity required of any individual shank length exceeds about 1000, the cost of the rivets will be considerable on account of the setting up time necessary. Furthermore, aluminium structures are not at present being fabricated in sufficient numbers to justify the production at an economic rate of quantities which could then be held in stock against future demands. For quantities up to 1000, it is worth-while examining the economies possible by machining rivets from bar stock. This will often be found to give up to a 40% saving in costs.

Design of Rivet Points

Since it may not always be practicable to resort to methods such as hot driving, much attention has been paid to developing a technique which would enable rivets of $\frac{7}{8}$ in. dia. to be cold driven on site with a pneumatic hammer. Mention has already been made of the fact that a Pan point appeared to be most suited to hammer driving, and experiments were, therefore, made with Pan heads (B.S.275). Since a reduction of the base diameter from $1{\cdot}6D$ to $1{\cdot}4D$ and the height from $0{\cdot}7D$ to $0{\cdot}6D$ gave a useful reduction in driving time, calculations were made to establish the smallest point (and head) size required to ensure that, even under tensile loading, fracture of the rivet would occur in the shank. These showed that a minimum base diameter of $1{\cdot}25D$ and height of $0{\cdot}42D$ would be adequate. Shear and tensile tests with several small Pan point shapes showed the calculation to be correct. These tests, together with experiments on other shapes made by Barlow and the author, are reported elsewhere[5]. For practical purposes, a small pan of $1{\cdot}4D$ diameter at base and $0{\cdot}4D$ in height is usually employed (Fig. 4*a*).

Experiments were then made to effect further improvements in driving by removing metal from the central portion of the rivet. At the same time, but independently, Whitman[6], of the Ministry of Supply Experimental Establishment, Christchurch, had been working along similar lines, and had developed a rivet with a tapered hole drilled out of the centre which, when driven, was essentially a small pan shape with a central recess. Whitman's rivet only had a base diameter of $1{\cdot}25D$ and a height of either $0{\cdot}25D$ or $0{\cdot}32D$. Owing to the possibility of rather oversize holes being used in practice, it was felt necessary, when using this shape for general purposes, to modify it by increasing the diameter of the base to $1{\cdot}4D$, whilst maintaining the height at $0{\cdot}32D$. These dimensions are usually exceeded in driving, and the strength of the rivet in direct tension is equal to at least 80–85% of the strength in the shank (failure being by shearing in the point); this is acceptable to most engineers. The dimensions of this shape, usually called the Recessed point, are given in Fig. 4*b*.

During this period parallel development work had been proceeding in Canada, and an Annular point (Fig. 4*c*) had been developed[7], which derived from a central drilled hole in which the centre point of a snap (driving set) was located. The hammer is rolled around through an arc of 5°–10° during driving. With the Recessed point, it is preferable to drive with the hammer vertically over the rivet, and only use the rolling action

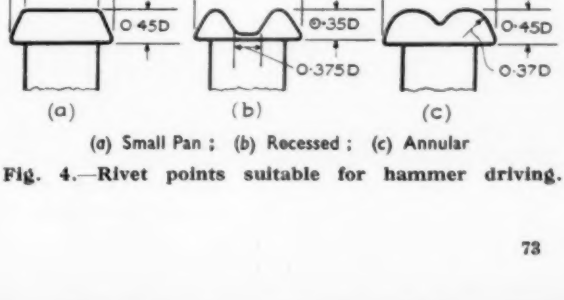
Fig. 3.—Rivet heating furnace for site use.

to finish off the edge of the driven shape, since the shape is designed to keep the metal in compression until the last moments of closing. As the Annular point usually has a finished base diameter of about $1{\cdot}5D$ and a height of $0{\cdot}45D$, it is a little more difficult to drive than the Recessed point, but, when both are of similar overall dimensions, there is little to distinguish them except that Recessed points are of rather better appearance.

Some tests are also in hand on the optimum dimensions for Countersunk points, which are much used in shipbuilding. Preliminary results indicate that, over a wide range of conditions, the angle and depth of the countersink are not of major significance. Large included angles, such as 90°, make the point more difficult to drive and hole filling less certain with deeper countersinks; small included angles tend to give rather less hold on the plates. For most purposes, a 60° countersink of depth equal to half the rivet diameter is satisfactory.

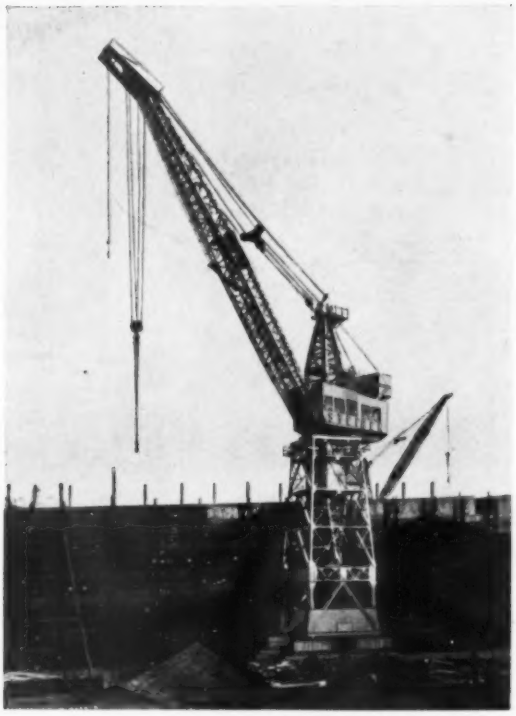
Recently Completed Structures

During the past year, several structures have been completed embodying the principles already described. The first of these was a 130-ft. crane jib (Fig. 5) for a 35-ton monotower crane[8] fabricated by Butters Bros. Ltd., Glasgow, containing 16 tons of aluminium assembled with hot-driven $\frac{3}{4}$-in. dia. N6 rivets and cold-driven $\frac{7}{8}$ in. dia. H10-WP rivets, the latter being used for highly stressed connections. This was the first



(*a*) Small Pan; (*b*) Recessed; (*c*) Annular

Fig. 4.—Rivet points suitable for hammer driving.



Courtesy of Butters Brothers, Ltd.

Fig. 5.—General view of 35-ton monotower crane with 130-ft. jib.

structure in the world to use cold-driven $\frac{7}{8}$ in. dia. aluminium alloy rivets. Two further jibs have since been completed. This year also saw the opening of a twin-leaf bascule bridge at Aberdeen[9] (Fig. 6), which was fabricated by Head, Wrightson Aluminium Ltd., in aluminium alloy, using $\frac{3}{4}$ in. and $\frac{7}{8}$ in. dia. N6 rivets. The Recessed point was mainly used for the structures, and the slightly higher cost of drilling the tapered hole in the end of the rivet was felt to be more than outweighed by the improved ease of driving.

Recognition of the valid case for smaller points on aluminium alloy rivets than the standard points on steel has been extended to the manufactured head, and the smaller shapes are now incorporated in B.S.1974 " Large Aluminium Rivets." In addition, this standard contains an appendix on recommended practice for driving aluminium rivets.

TABLE III.—MAXIMUM SIZE OF RIVETS DRIVEN BY NORMAL EQUIPMENT.

Method of Driving	Condition	N.A. Cone	60° CSK	Small Pan	Recessed
Squeeze	Cold	$\frac{7}{8}$ in. or more	—	$\frac{3}{4}$ in.	—
Pneumatic Hammer	Cold	—	$\frac{5}{8}$–$\frac{3}{4}$ in.	$\frac{3}{4}$ in.	$\frac{7}{8}$ in.
Pneumatic Hammer	Hot or freshly quenched	—	$\frac{3}{4}$ in.	$\frac{3}{4}$ in.	1 in.

TABLE IV.—MINIMUM SHEAR STRENGTH FOR DRIVEN ALUMINIUM ALLOY RIVETS.

Alloy	Condition of Driving	Shear Stress (tons/sq. in.)
N4	Cold	8
N5	Cold	10·5
N6	Cold	12
N6	Hot	11
H10-W	Cold	11
H10-WP	Cold	13
H13-T	Cold	12
H14-T	Freshly quenched	18

It might, therefore, be advisable to summarise in Table III the recommendations indicated from combined test work and practical experience. The figures for squeeze driving are based on the assumption that 40/50 tons force is exerted. Obviously, larger rivets can be driven with a bigger machine. With hammer driving, these figures apply to N6 rivets, but the behaviour of H10-W, H10-WP and H13-T rivets is similar. For freshly quenched H14-T rivets, $\frac{7}{8}$ in dia. is the maximum practicable size, using Recessed points. The hammer employed is of 9 in. stroke × $1\frac{1}{16}$ in. bore, usually known as a " 90."

The driven rivets are normally rather stronger than the rivet stock, due to cold working in driving. Hot-driven rivets in the aluminium-magnesium alloys do not show this increase, and rivets in H10-W or H13-T driven in the freshly-quenched condition usually give properties about 5% lower than those driven after ageing is complete. The minimum shear values for driven rivets,

Courtesy o Head Wrightson Aluminium Ltd.

Fig. 6.—Aluminium twin-leaf bascule bridge at Aberdeen.

based on data obtained from A.D.A. work and fabricators tests, are given in Table IV.

Conclusion

This year has seen the culmination of five years' work on the problem of riveting large aluminium structures. Those structures completed during the last twelve months are evidence of the quick evolution from laboratory experiment to actual achievement. The combination of metallurgical and engineering skill and knowledge which they represent has enabled the claim to be justifiably made that the fabrication of riveted light alloy structures of large size is now practicable, and in this practice Britain leads the world.

Acknowledgments

The Aluminium Development Association takes this opportunity of recording very sincere thanks to the following: Baxter's (Bolts, Screws and Rivets), Ltd., Guest Keen and Nettlefolds, Ltd., and J. Stone & Co. (Deptford), Ltd., for assistance in manufacturing the rivets used in these tests; the Brighton Works of British Railways (Southern Region) and Horseley Bridge and Thomas Piggott, Ltd., for facilities for carrying out driving tests; Broom and Wade, Ltd., Climax Rock Drill and Engineering Works, Ltd., and Consolidated Pneumatic Tool Co., Ltd., for assistance in experiments with pneumatic tools; and Member Companies of the Association for supplies of materials, for examination of joints, and for other facilities.

Courtesy of Head Wrighton Aluminium, Ltd.

Fig. 7.—Riveting sections of the Aberdeen bridge.

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Aluminium Skyscraper

THE recent war proved to be a tremendous stimulant to the alumium industry, and production and fabricating capacity increased enormously. With very few exceptions, production was allocated entirely to the needs of war; it is not suprising, therefore, that, on the conclusion of hostilities many believed that the industry, deprived of this stimulus, would languish and shrink. Events proved this forecast to be inaccurate and today aluminium is of much greater industrial importance than it was prior to 1939.

Shortly after the war, the aluminium industry directed considerable attention to the many possible peaceful applications for this material. Of these, not the least important was the great contribution the industry made in helping to meet the housing problem with the design and production of temporary bungalows. So rapid were the developments resulting from the construction of these earlier dwellings that, for some years now, aluminium buildings have been erected as permanent structures.

Although the progress in this field has been such as to establish a new industry in this country, evidence of the importance of aluminium to the building industry is emphasised by the recent opening of the new office building of the Aluminum Company of America. This building, claimed as America's first aluminium skyscraper, is a 410 ft. 30-storey building, whose exterior walls are sheathed with hundreds of aluminium panels. Its aluminium windows are reversible so that they can be cleaned from inside the building; weather is kept out by means of an inflatable rubber tube recessed in the window's aluminium frame. Completely air-conditioned, the building's offices are heated and cooled from aluminium ceilings. All electrical wiring and most of the plumbing is aluminium, as are lighting fixtures, elevators, partition framing, and many thousands of pounds of interior trim.

The aluminium panels, which sheath the building in a continuous run, are $\frac{1}{8}$ in. thick and measure roughly 6 ft. $\times$ 12 ft., the top half containing a cut-out for the insertion of a reversible, aluminium-framed window. They are electrochemically treated to build up aluminium's natural oxide coating, and silicon-bearing alloy liner in the sheet itself, combined with this anodising process, provides a permanently iridescent grey colour.

A novel feature in this aluminium-sheathed building is the back-up wall. It is a thin, self-supporting lightweight barrier to fire, sound, and heat loss. Erected from within the building after the facing panels of aluminium were installed, the back-up wall was sprayed into place. Slotted aluminium laths were first set up as a form to receive the lightweight concrete inner wall, and metal reinforcing bars were simultaneously put in place. Next, a four-man crew sprayed perlite concrete from a pneumatic nozzle onto the aluminium laths,

Courtesy of the Aluminum Company of America

Alcoa building nearing completion.

after having first masked out the window areas. Four separate, 1 in. thick passes were made on the walls, the perlite hardening after each application before the next layer was applied. Experience showed that three of these four-man crews were able to complete back-up

Courtesy of the Aluminum Company of America

Installing the first aluminium panel and column cover.

walls of the building at the rate of about four floors a week.

It is claimed that the use of aluminium makes for faster and cheap construction. With regard to the former, mention may be made of a 26-storey office building in New York, which was finished off last summer with 1,800 aluminium panels, each two storeys high and 4½ ft. wide, in 6½ days. On the question of cheapness it is estimated that a metal panel can be put in place for about one-quarter less than it takes to give a finish to a building with masonry. It is lighter to handle, easier to maintain, and its use saves space inside the building.

This 30-storey building is located in Pittsburgh, but two similar buildings are under construction on Park Avenue, New York, while others are going up in Dallas and Denver. Further, it is understood that the Aluminum Company of America holds a considerable list of structures as office buildings, factories, banks, and such like, which have been planned to make use of aluminium sheathing.

While appreciating the great strides made in the application of aluminium to other industries, there can be no doubt that, in the field of building construction, considerable expansion in its use can be confidently expected.

B.C.I.R.A. Grinder Dust Control

REFERENCE was made in an article on The British Cast Iron Research Association, in the October, 1953, issue of METALLURGIA, to a method of dealing with the dust problem in pedestal or stand grinders generally used for foundry fettling. The principle is embodied in an external dust control unit, the use of which leaves the operator's breathing zone as free from dust as the general atmosphere. The Council of the Association has recently approved an arrangement whereby the manufacture of this unit and supply to the industry, either directly or through normal trade channels, will be handled by Air Control Installations, Ltd., Ruislip, Middlesex (Tel. : Ruislip 4066), and any enquiries about the installation of the unit should be directed to the Company or to its district offices in Glasgow, Manchester and Birmingham. The unit is suitable for converting existing pedestal grinders, or for use in new machines of existing design, but arrangements are also in hand for the issue of licences to makers of pedestal grinding machines for the incorporation of the arrangement as an integral part of new machines, rather than as an addition.

Congress on Surface—Active Agents

SURFACE active agents, which in their aqueous solutions possess valuable wetting, foaming, emulsifying and detergent properties, have undergone spectacular development in the last few years. The ever-growing number of these compounds and their varied species have led to members of the trade association, " Chambre Syndicale Tramagras," to organise the first World Congress on Surface Active Agents. This will be held from August 30th–September 3rd at the Sorbonne, Paris, and will be presided over by Professor Trefouel, Director of the Institut Pasteur. Further information can be obtained from Secretariat General du Ier Congres Mondial de la Detergence, 70, Champs-Elysees, Paris (8e). Telephone : BALzac 05–10.

Aluminium in the Textile Industry

By E. C. Roylance
High Duty Alloys, Ltd.

In the design of equipment for those branches of the textile industry dealing with man-made fibres, advantage has been taken of the properties of aluminium alloys from the start, but in the older branches, light alloys have found application by replacing cast iron, wood and paper. In this article, reference is made to some of the purposes for which aluminium and its alloys are being used in the textile industry.

THOSE who have followed the varying fortunes of the struggle to bridge the gap between imports and exports will be aware of the important role played by textiles. What is probably not so widely known is the extent to which light alloys are used in the textile industry, and the help which they have given in the drive for increased productivity. In those branches of the industry dealing with the man-made fibres, light alloys have been used from the start, but in some of the older branches, such as cotton and wool, they have been used to replace cast iron, wood and paper.

Light alloys were used to a limited extent before the war, but the post-war years have seen a considerable increase in their application to the design and construction of textile machinery, components and accessories. Increased production at lower cost could only be achieved either by installing more modern plant, or by operating existing machinery at higher speeds. A considerable speed increase of existing machines, without any modification to them, would result in an increase in the stress factors, rapid wear and a considerable rise in maintenance costs, which in all probability would wipe out any saving made in the cost of production. Furthermore, the developments in regenerated fibres such as viscose and acetate rayons and the synthetics—nylon, Terylene, etc.—introduced difficulties, in that the higher strengths of some of these fibres, and the denser yarn packages, resulted, in certain circumstances, in bobbins and beams manufactured in wood or paper collapsing under the pressure applied. To problems such as these, aluminium and its alloys, with a specific gravity about one third that of steel and an ultimate tensile stress of up to 38 tons/sq. in., provide an obvious answer.

Apart from their properties, aluminium alloys have the added advantage that they can be produced in a wide range of forms. Besides sand, gravity and pressure die castings, which can replace many of the cast iron parts, these materials can be produced as tube, sheet, extrusions and forgings. In addition, the machining operations can be carried out at higher speeds than are possible with most other commercial metals, and fine limits of dimensions obtained. Finally, beams and bobbins made of wood have negligible scrap value, whereas aluminium components retain a certain value, in that they can be re-melted in the production of secondary aluminium alloys, and thus effect, over a number of years, considerable saving.

Early in 1947, a group of technical engineers from High Duty Alloys, Ltd., visited the U.S.A. to study the use of aluminium in the American textile industry. They had access to many of the most important users of beams and bobbins, and it was found that considerable advantage was being gained by the use of light alloys, and the manufacture of these components was being undertaken on a very large scale. It was observed that the size of the beams being produced was far larger than in our own textile industry; beams 84 in. in length, with flanges up to 36 in. in diameter and barrels up to 10 in., were in operation. Also, spinning bobbins were being manufactured to carry yarn up to 2½ lb., and plans were well ahead to increase this to 8 lb. The working surfaces of the bobbins were given a thin coating of either Vinylite or Perspex, but a section of the industry preferred to leave the surface with a machined finish.

[Fig. 1.—A group of aluminium alloy textile bobbins.

It was considered that the American and British methods of production were progressing on very similar lines. The only points at which they varied were in fabrication, but each process had its advantages.

Spinning and Doubling Bobbins

One of the outstanding applications of aluminium alloys in the textile industry is in the manufacture of bobbins of various types. If a textile bobbin is produced in true rotational balance, then its speed in operation can be much higher without increasing the stresses caused by centrifugal forces, vibration, etc. The

Fig. 2.—Grinding extruded tube for textile bobbins.

excellent machining properties of the aluminium alloys used for these bobbins, together with the high efficiency production methods used in their manufacture, ensure fine dimensional tolerances with uniformity of balance, which make possible much higher yarn speeds in drawing, spinning, doubling and creping of all types of yarn.

As will be seen from Fig. 1, the majority of bobbins consist of two end flanges, joined by a central barrel. The latter is produced from extruded tube, by parting off the appropriate length, followed by centreless grinding of the outside diameter (Fig. 2), to ensure perfect balance. This is followed by a boring operation on the two ends, the location being taken from the outside diameter. The flanges (Fig. 3) can be produced as sand, gravity or pressure die castings, the latter being the most economical process when the cost of the dies can be spread over large numbers of castings. The flanges are machined to close tolerances before being fitted on to the barrel. There are two methods of fixing; by means of an interference fit, or by the use of adhesives.

In the first method, the barrel is centreless ground to have an interference fit when mated under pressure with the internal bore of the flange. The second is a more lengthy process, in which the end spigot of the flange is coated with a patented thermal adhesive before mating with the barrel under pressure. After assembly, the bobbins are given a low temperature treatment before testing at a load of 2,000 lb./sq. in.

Light alloy bobbins possess good resistance to corrosion, but added protection can be achieved by anodising, which also tends to reduce wear. Furthermore, by following the anodising with a dyeing operation, the colour of the bobbins can be used as a means of indicating the yarn count or denier, according to a pre-arranged scheme. The successful outcome of the use of aluminium alloy spinning bobbins, without doubt, had a great influence on the adoption of light alloys for the production of other components.

Condenser Bobbins

In the re-design of condenser bobbins for use in carding and spinning woollen blends, cotton waste and similar types of materials, it was found that the ideal was a simple transformation, the wooden barrel being replaced by an aluminium one. The barrel is given a shot blast surface, or in some cases a faint knurling, and the flanges are made in blue steel, being fixed to the barrel by a steel nut and spigot. In the change from wood to light alloy, the weight is often reduced—a very important point in winding and drafting these yarns—and it is, therefore, possible to increase the capacity of the bobbin and lower the frequency of bobbin changing, and, in this way, to save a considerable amount of time. The light alloy bobbin is also less liable to damage through misuse in the mill.

Condenser bobbins range from 2 in. to 4 in. barrel diameter, with flanges up to 12 in. diameter, and owing to the range of sizes in which aluminium alloy tube is available, considerable scope is offered to the mill manager in determining his exact requirements.

The price of aluminium alloy barrelled condenser bobbins is very competitive with the wooden barrel type, and as a greater life can be expected, it is of distinct interest from the point of view of mill economics. An additional advantage is that the light alloy barrels avoid the risk of injury to operatives and damage to yarn which may be caused by wood splinters.

Warp Beams

Owing to the high speed being called for in warping, the beams require to be perfectly balanced, and, as in the case of spinning bobbins, light alloys are especially suitable, due to the ease of manufacture to very close tolerances. The flanges are sand or gravity die-cast

Fig. 3.—Aluminium alloy bobbin flanges.

with a cast iron insert which can be screwed to fit the barrel. The flanges are machined on the contact face to ensure perfect alignment when assembled on the barrel, and also on the inner face, to prevent snagging of the yarn. The barrel is made from extruded or drawn tube, machined on the outside diameter to a tolerance of ± 0·002 in., and screwed at each end to allow for adjustment of the flanges for different warp widths, the flanges being locked in the required positions.

The final operation is the machining of the knot holes for the yarn at 6 in. to 12 in. centres. If ruffles are required, they are supplied as separate units, made by casting an alloy centre together with a cast iron ring, which is finally machined on the outside. They can be fitted as a loose attachment by means of a locking nut on a square beam spindle. The flanges are designed with six ribs to give maximum rigidity, and Fig. 4 shows a typical warping beam with an overall length of approximately 60 in., width between flanges variable between 43 and 56 in., diameter of flanges 16 in., diameter of barrel 4½ in. and a weight of 56 lb. This beam is capable of carrying 160–180 lb. of yarn. Warp beams are now being produced up to 83 in. long with 36 in. diameter flanges and 10 in. diameter barrels, dimensions which, without the use of aluminium, could not have been considered.

Fig. 5.—Warp beam flange, gravity die cast in Hiduminium 20.

Beam Flanges

There is a constant demand for beam flanges throughout the textile industry, and in many Lancashire mills primarily concerned with the weaving of cotton yarns, the general practice was to use comparatively lightly constructed beams. Any flange used with these wooden barrels must of necessity be light in weight and at the same time strong and durable. After considerable investigation, it was found that a suitable flange could be produced by pressure die casting. This would ensure reasonable accuracy in dimension and balance, and also eliminate the possibility of yarn snagging, by having a smooth surface finish. Finally, it could be produced in quantity and sold at a competitive price.

Today, beam flanges weighing 3½–5 lb. can be supplied with outside diameters of 17 or 18 in., and bore sizes ranging from 4–5 in. The methods of fixing are simple, but effective; set screws are screwed through the bore and flange, which has been given a slight taper to allow the insertion of wedges as an additional precaution. The second method is to cast lugs on the outside of the flange, which forms a split circular clamp round the barrel, and this can be tightened by the use of Allen screws.

For beam flanges to be used in rayon and silk weaving, it was considered that pressure die castings would not stand the considerable outward pressure exerted by the yarns, and flanges for this purpose have been produced as gravity die castings (Fig. 5) in B.S. 1490 : LM 8. In the heat treated condition, this alloy has an ultimate tensile stress of 15 tons/sq. in., and the flanges can be supplied from 18 in. diameter with 4–5 in. bore, to 26 in. diameter with 5–6 in. bore, and are made with a half clip for fixing to the light alloy barrel. Even at 26 in. diameter, these flanges are still inside the safety factor for weight. Due to the surface of these castings not being as smooth as those of a pressure die casting, the inside surface is machined to avoid any possibility of yarn snagging, as well as to ensure squareness with the barrel.

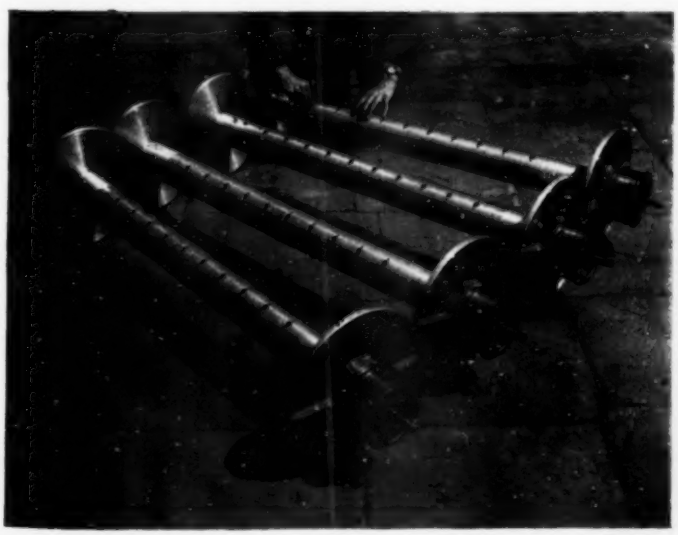

Fig. 4.—Aluminium alloy warp beams showing flanges, knot holes and ruffles.

Weft Pirns

Pirns are now being manufactured successfully as pressure die castings in aluminium alloy, and any type can be manufactured so long as the quantity required makes it an economic proposition. Light alloy pirns show to the best advantage when used with nylon, rayon or Terylene yarns, as they are much stronger than the wooden pirns normally used. They can be machined to very close tolerances and anodised to give a smooth and protective surface.

Assistance has been given to the production

Fig. 6.—Forged and machined aluminium alloy spinning pots.

of light metal pirns by the formation of committees to standardise all types of weft pirn. Copies of the new standards can be obtained from the British Standards Institution.

Centrifugal Spinning Equipment

One of the latest applications of aluminium in the textile industry concerns the centrifugal spinning process. This system was developed in this country to offset the changing economic conditions of the industry. Scarcity of labour had produced in its train very high conversion costs, and to reduce this, mechanisation has been used to the highest degree, thereby utilising to the full the reduced labour force. Maximum production per operator, increased range, flexibility, and larger capacity packages than are possible with conventional types have been the major aims, and in accomplishing this, aluminium alloys have played a very important part.

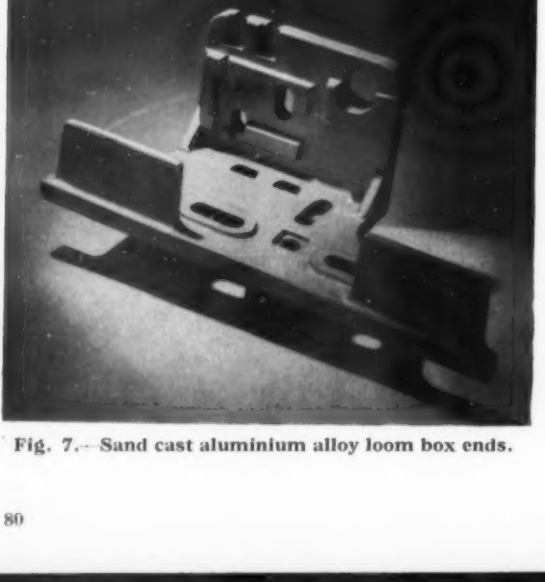

Fig. 7.—Sand cast aluminium alloy loom box ends.

Spinning containers used on the centrifugal machines are being made as drop forgings in Hiduminium RR 77 (DTD 683) as shown in Fig. 6. This alloy has the following tensile properties: ultimate tensile stress 32–34 tons/sq. in.; 0·1% proof stress 27–31 tons/sq. in.; elongation 10–15%.

Spinning containers have also been made in 99·5% purity aluminium and in Hiduminium 44 (AW 10B). The latter alloy, in the heat-treated condition, has an ultimate tensile stress of 18–19 tons/sq. in.; a 0·1% proof stress of 15 tons/sq. in.; and an elongation of 7–10%.

Due to the acids used in the process, these two materials are particularly suitable for the spinning of viscose yarns, as they have a very high resistance to corrosion. After forging, the containers are machined to very close tolerances and then dynamically balanced so as to ensure the very minimum of vibration when running at speeds up to 14,000 r.p.m. Another method of production is to use die forgings for the top ring and bottom shank, the centre part being made as a back extruded tube. These components are then machined to close limits, screw fitted and dynamically balanced.

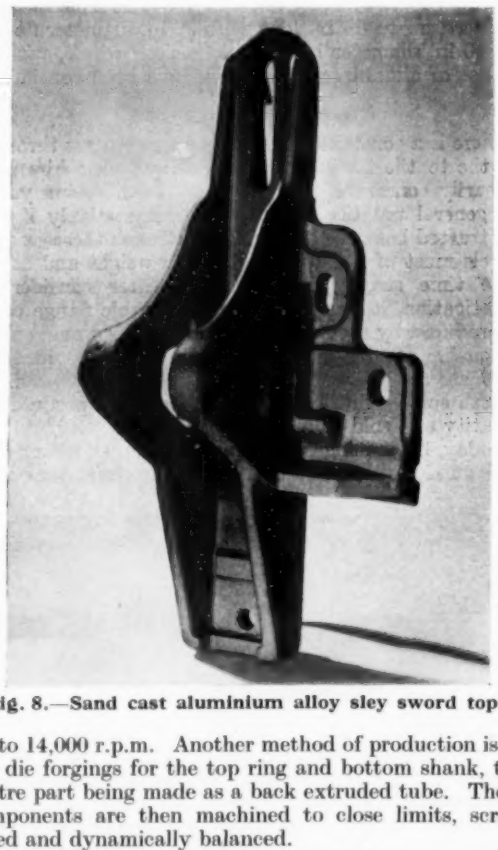

Fig. 8.—Sand cast aluminium alloy sley sword top.

Spinning and twisting bobbins made to a special design in aluminium alloy have been used with great success in the centrifugal spinning process.

Miscellaneous Machine Applications

The use of aluminium alloys in the textile industry has not been confined to bobbins and beams. Full advantage has been taken of its properties by the textile engineer and machine designer at almost every stage of production. They have fully realised that, to allow British

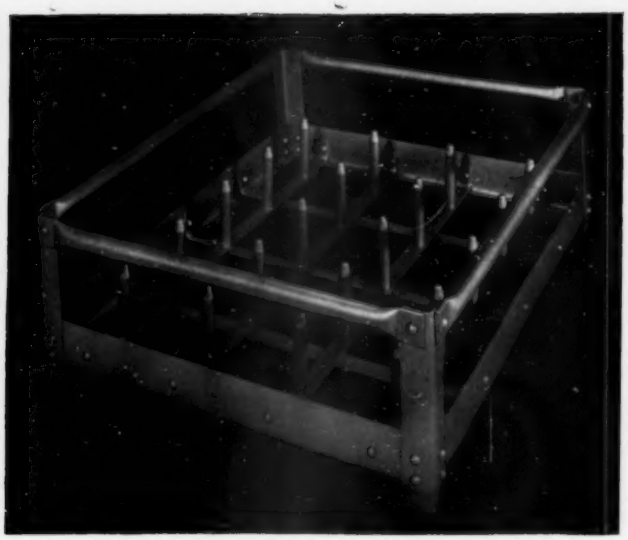

Fig. 9 (left).—Gravity die cast aluminium alloy weft thread guide for automatic loom pirn battery.
Fig. 10 (right).—Yarn cheese or cone crate fabricated in aluminium alloy.

manufacturers to compete in the world markets, looms must be designed to operate at higher speeds with fewer stoppages and mechanical breakdowns. In an endeavour to achieve this, considerable attention has been given to reducing the weight of reciprocating parts in automatic and non-automatic looms. As a result of this, many components formerly made in cast iron are now made as gravity die castings in Hiduminium 40 (B.S. 1490 : LM8), or Hiduminium 20 (B.S. 1490 : LM4) and have a higher strength ratio, but considerably reduced weight. A few of the items on which the change has been successfully made include sley swords, box ends (Fig. 7), sley sword tops (Fig. 8), check brackets, drop covers, battery stands, thread guides (Fig. 9), groove pulleys and guards, whilst sley caps have been produced as hollow extrusions.

In carpet looms, there is a tendency to replace with light alloy the chain and stuffer beams which at present have a mild steel barrel and malleable iron flanges. Due to the limited amount of space between the loom sides, a special design was necessary which made use of cast flanges in the fully heat treated LM8 alloy.

Aluminium alloys have also played an important part in the development of fancy and worker rollers in wool carding machines, as they are light, strong and durable, easy to handle and offer economies in power consumption. Rollers have been made as sand castings in LM8 with diameters ranging from 6 in. to 10 in. Suitable ribs on the inside give added thickness for fitting the wooden blocks to which the card clothing is nailed. The guards on this particular machine have been specially designed and manufactured as sand castings in LM4 alloy.

Attention has also been directed towards equipment used for conveying between operations, and creels, pirn trays and bobbin trays (Fig. 10) are now fabricated in aluminium alloys—a procedure which improves the transport position.

Conclusion

To summarise the outcome of the application of aluminium and its alloys to the textile industry, it can be said that it has been successful, but it must be emphasised that only one aspect of the developments has been touched upon in this article. Many of the reasons advanced can be applied with equal force to an extensive range of equipment. Nor are the problems encountered solely those of a mechanical nature associated with the dynamics of components rotating or reciprocating at high speeds. Resistance to corrosion and chemical attack is demanded both as regards non-staining qualities, where the finished products come into contact with metal, and for use in many cleaning and dyeing operations. Aluminium can be used in all these essential processes, providing an accessory having an indefinite life, mechanically strong, resistant to chemical attack and readily shaped to almost any form at an economical cost.

Analytical Chemistry Symposium

As has been announced previously, the Midland Society for Analytical Chemistry is holding an eight-day Symposium on Analytical Chemistry at the University of Birmingham, from 25th August to 1st September, 1954. A number of original papers are to be contributed by British and overseas authors, and recent advances in industrial applications and special techniques will be discussed. In addition, there will be three plenary lectures given by speakers of international repute.

Apart from the meetings, there will be an exhibition of apparatus, reagents and scientific literature, embodying the latest developments in analytical chemistry ; and a special exhibition of historical chemical literature, including the Joseph Priestley collection, will be on view in the Harding Library. Demonstrations will also be given of new analytical techniques. A number of visits of scientific and general interest have been arranged to local industrial establishments, whilst the social functions will include a Symposium Dinner and a Civic Reception. In addition, a number of special visits will be arranged for lady visitors. Registration forms and further information may be obtained on application to the Symposium Secretary, Dr. J. W. Robinson, Post Office Engineering Department, Birmingham, 9.

Aluminium and its Alloys in 1953

Some Aspects of Research and Technical Progress Reported

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The Aluminium Development Association.

Attention is drawn to published work reporting research and technical progress in the various aspects of the metallurgy of aluminium and its alloys, including extraction, founding, fabrication, constitution and properties.

THERE is a famous story in the North of England about a millowner many years ago, who, reading about scientific progress and the advantages to be gained in efficient production and cost reduction by technical control, decided to engage a young graduate in his works. At the end of the new member of staff's first day in the mill, he was summoned by the owner, who, in the forthright manner of his kind demanded, "Now lad, has tha discovered owt?" Although we do not look for quite such rapid progress to-day, applied science—as distinct from the pure variety—is expected to pay its way, albeit somewhat in arrear, and, indeed, it almost always does, and with considerable interest. To read, year by year, only a part of the published literature in one language on one technical subject is to realise how fast and how far science and technology are moving, and how easy it is for the reader to be left behind.

The year 1953 is notable as the fiftieth anniversary of an event the effect of which upon humanity is still hardly guessed at, namely, the first controlled flight of a powered heavier-than-air machine by the brothers Wright at Kitty Hawk. Although the commercial history of aluminium begins properly in 1886, there has been a very close parallel between the rapid development of the metal and that of aircraft; since about 1920, aluminium alloys have been the main structural material for most types of flying machine, and at present there is no serious competitor in view. Furthermore, the experience gained in developing alloys for aircraft has been put to good use in other fields, so that to-day, despite its importance, the aircraft market takes only a fraction of the world's aluminium production.

Production

It was in 1953 that the world learned for the first time that volume output of aluminium was exceeding that of all other non-ferrous metals together; during the same year the metal shortages of the world came to an end, with the exception of a slight remaining scarcity of aluminium in the U.S.A. Anderson[1], the former Deputy Administrator for Aluminum, Defense Production Administration, has surveyed the possibilities of increase in demand for aluminium in the U.S.A. and he notes that an estimate of 5% per annum per capita seems, if anything, conservative. The effect of stockpiling is considered, and the point is made that in any future war it would be essential to have "enough on time" rather than "too little too late." The paper is illustrated by some very informative graphs showing the increase in per capita consumption of the major metals during this century, from which the venturesome might extrapolate, but one particular figure given catches the eye, since it is information of a type seldom quoted. Anderson states that a typical alumina plant, with a capacity of 1,000 tons of alumina per day, now costs between 40 and 50 million dollars. This gives some idea of the tremendous capital required to establish an aluminium extracting industry.

Although an article by West[2] on the aluminium supply position is chiefly devoted to the needs of this country, he brings out more clearly than Anderson how the industry is essentially international, and how prices in one country are affected by such factors as appreciation of currency values in another. Having reviewed the new and expanding facilities for aluminium reduction, the author considers how the new output is to be utilised, and notes that while price changes might have made somewhat harder the task of developing aluminium applications, the long term prospect is bright. He ends with a plea for every effort to apply the results of basic investigations, and notes that building is a field offering ample scope for this.

Melting and Casting

Exceptions such as powder metallurgy only go to prove the rule that the first stage in the fabrication of metal is melting and casting, and with much of the aluminium used it is also, of course, the last, except for fettling, machining and finishing. In a series of articles, McIntyre[3] has considered both billet (or ingot, according to branch of industry or personal taste) and casting production, and has summarised present practice in each field, for iron and steel and non-ferrous metals. The references quoted form a useful bibliography, and the author has taken care to clarify by well-chosen illustrations the various branches of the casting art.

Ingot (or billet) production is nowadays so distinct from the manufacture of castings that most authors consider the two enterprises quite separately. The appearance of a book on the casting of non-ferrous ingots by such noted authorities as Aitchison and Kondic[4] is to be welcomed, and they have succeeded in viewing the subject as an entity, and not simply a collection of sections on the various metals and their alloys. As might be expected in a book from this source, the practical production aspects are not submerged in the theoretical and metallurgical treatment.

A particularly interesting chapter tracing the development of metal working brings out clearly the way in which the ability to work large pieces had to wait for the availability of the necessary power to handle them: as the authors state, human muscles are limited, and horses could not be trained to wield either tongs or hammers. The book is well summed up by the three words the publishers have printed on the dust jacket: "A Complete Treatise."

Two symposia were held in 1953 on aspects of melting and casting. That at Birmingham University[5], on the continuous casting of metals, centred round papers by Kondic on metallurgical and engineering problems, and by Crowther on the process itself. The latter author states the advantages and drawbacks of aluminium alloys generally as subjects for semi-continuous casting, notably their high shrinkage, and also compares the various groups of alloys from the point of view of castability, noting that the high strength aluminium-zinc-magnesium-copper types are particularly difficult to cast into large billets. Both authors mention the voluminous patent literature on continuous casting, since Bessemer first protected his direct rolling ideas about a century ago.

The other symposium, organised by the Institute of Metals, was rather more specialised, being concerned with the control of quality in melting and casting non-ferrous metals for subsequent working. The paper on aluminium alloys was by Staples and Hurst[6], and the complexity of the problems involved may be judged from the fact that seven classes of billet and nine alloy groups are discussed, and in these groups, freezing ranges vary from 20° C. to 170° C., to select but one variable factor. The degree of control exercised by physical and chemical inspection is described, together with the limitations of the melting and casting processes available.

Turning to work associated with casting production, an interesting note has been published by Michael and Bever[7] on the modified aluminium-silicon alloys. By reference to published work, they illustrate the difference of opinion as to the explanation of modification, and the function of sodium. By the use of radioactive sodium fluoride, and an autoradiographic technique involving an emulsion film applied to a very thin metallographic specimen, the distribution of sodium in a modified aluminium-7% silicon alloy is demonstrated by black dots caused by disintegrating Sodium 24 atoms. The sodium is shown to be equally distributed in areas of eutectic and primary constituent, thus establishing that there is no special association of the bulk of the sodium with the silicon. Mascré[8], working with hypereutectic alloys containing 22% of silicon, has shown that phosphorus, as aluminium phosphide, successfully provides nuclei for crystallisation of the silicon, and results in fine structures and improved strengths, whereas sodium, by increasing the viscosity of the liquid aluminium, changes the silicon crystals into globular form, with corresponding impairment of mechanical strength. Particular reference is made to the advantageous effects of phosphorus modification on machinability.

The work of the British Non-Ferrous Metals Research Association on the prevention of metal/mould reaction in sand-cast aluminium-magnesium alloys is well-known, and Whitaker[9] has now published an interesting account of work providing confirmatory evidence that beryllium is the best metal addition to inhibit this phenomenon, and that minimum reactivity is found with 0·004% present. The author used small cylinders of alloys heated in steam, and assessed reactivity by changes in weight. A formidable list of other additive metals was tried, and these had slight beneficial effect, but none approached beryllium in efficiency. It is also shown that, of the impurities likely to be present in aluminium alloys, only sodium is harmful to the inhibitive action of beryllium.

Sully, Hardy and Heal[10] have sought the reason for the thickening of alkali chloride fluxes used in remelting finely divided aluminium alloys, a phenomenon which results in entrapment of fine metal in the flux. The effect is shown to be due to an increase in viscosity produced by the presence of alumina films, stripped from the metal being melted; this is particularly marked with thin flat films. The thickness of the flux can be reduced by stirring, and appreciable quantities of entrapped metal agglomerated and released; unfortunately this does not apply to particles of 100 mesh or finer.

A new planet which has swum into the ken of the foundryman during the last few years is shell-moulding, and much ink has been spilt in describing it and its advantages and drawbacks. It is useful, therefore, to have a general summary of the process, and Ames[11] has provided this, discussing most aspects, including both metallurgical factors and shop-floor details, and, of great importance, economics. Perhaps one sentence sums up the author's views, and is worth quoting: "The process, although promising, should not be considered a panacea for all foundry ills." In other words, while it is a most useful addition to the founder's technique, the advent of shell-moulding, as with so many other technical advances, does not usher in the millenium.

Another useful tool of the founder is the Antioch process of plaster moulding, and a description has been published [12] of its use by an American company for making tyre moulds, an application well-known in this country. While mere size is, perhaps, not a great attribute, nevertheless Harrison's[13] account of the production of a large aluminium alloy (LM6) wheel is of interest, in view of the problems encountered by the foundry and the methods of overcoming them. The wheel was 15 ft. in diameter, and was cast in two halves, 3,310 lb. of metal being melted for each casting, the finished fettled job weighing 2,250 lb.

The best way to ensure a leak-proof casting is to avoid porosity, but this is extremely difficult with many aluminium alloys. Impregnation has, therefore, on occasion to be resorted to, and Pratt[14] has described the advantages of the newer sealants based on synthetic resins such as polyesters and styrene. He shows that a correctly impregnated casting is less liable to corrosion, since ingress of aggressive agents is prevented. The author also claims that porous castings may be successfully anodised after impregnation.

Working

The aircraft designer has long been attracted by the idea of abandoning many of his sub-structures at present fabricated from sheet and extrusions, and replacing them by large forgings. One of the slogans of his trade is the famous "simplicate and add more lightness," and by the above means weight can be reduced and strength and stiffness increased at the same time. At any rate, this is true in theory, and cannot be truly assessed in

practice until some Western country possesses a sufficiently large forging press to put the matter to the test. (The largest press in the world—30,000 tons—is on the other side of the Iron Curtain.) The nearest approaches to such a press in this country are two, each of 12,000 tons capacity, one of which was recently installed, after extensive modification, by a company in the Midlands[15 16]. No doubt experimental work with it will help to provide most valuable data, and at the same time it will be able to produce the largest forgings required by jet engines.

Things are usually larger in America, and heavy presses are no exception to the rule; the U.S. Air Force has on order two 50,000-ton and two 35,000-ton forging presses. One of each has been designed by an American company and they are now being built. Cohan[17] has described the special problems involved in forging the steel columns for such giant pieces of equipment. For the larger press, each of the six columns has three laminations, and each lamination weighs 145 tons and requires a 275-ton steel ingot for its manufacture. The foundations for the press are 100 ft. deep, with supporting walls of concrete 13 ft. thick. Such details give some impression of the enormous cost of an installation of this type, and of the courage of those entering a field about which little is known, and where there is no guarantee that the forgings eventually produced will justify the expense and effort.

Some of the difficulties likely to be encountered are described by Schor[18] in reporting on a symposium on large forgings and extrusions for aircraft, held in New York. A particularly important one is that such large products require large sound billets, and to cast these presents many problems, particularly with the very high strength alloys in increasing demand for modern aircraft construction. It is gratifying to find a reference in this account to the British work on the causes of hot shortness in aluminium alloys, now so well-known and appreciated in this country.

Before forgings can be made, billets must be heated, and Barfield[19] has described an induction heated furnace for aluminium alloy billets which employs main frequencies. Although nearly half the energy is lost as heat generated by the primary current, the output obtained in lb./hr. for a given power consumption compares favourably with that of batch type furnaces.

Much has been written about the wonderful continuous aluminium strip mill at Rogerstone, but Peck's[20] account of the electrical controls involved is a useful reminder of the great complexity of modern equipment of this type, and even readers whose electrical knowledge extends little beyond fuse-mending can appreciate the principles involved.

Working with Brillalumag, an aluminium-3% magnesium alloy based on aluminium of 99·95% purity, Hérenguel[21] and his colleagues have studied the mode of deformation of single crystals subjected to progressive rolling reductions. They show that this proceeds by a mechanism analagous to that observed by other workers who tested single crystals under tension and compression. The authors emphasise that X-rays would not have produced the information secured by micrographic methods, as they give only a statistical average, whereas the phenomena observed often concern bands as thin as 2 microns.

Hinxman[22] has commenced a most useful task in providing a series of articles on the forming of aluminium and aluminium alloy sheet, and in his section on bending it is interesting to see a table giving both specification bend radii and typical values for a 180° bend at various thicknesses. This type of information is much in demand, but is so hedged around with the effect of various factors, such as grain direction, edge condition, and tool condition, that in practice it is usually necessary to make trials if it is essential to have the sharpest possible bend.

It is difficult to give a treatise on the deep-drawing of aluminium alloys in four pages of a journal, but Sachs'[23] review is nevertheless instructive, and brings out clearly the effect of alloy composition on drawability, and the importance of having the stronger alloys in truly soft condition, if success is to be attained. The measurement of suitability for deep drawing has long been the subject of experiment and conjecture, and Pearce[24] has combined with a research intended to select the best aluminium alloy for the mass production of motor-car bodies, a comparison of the cupping test devised by Professor Swift with the ordinary tensile test. Working with various aluminium-magnesium alloys, he shows that, while the two methods are in general agreement when the cupping press uses the round punch, the flat-bottomed punch differs in its assessment, and in Pearce's view is the more discerning test. The annealed aluminium-5% magnesium alloy (NS6–O) is selected as the best all-round material for press work.

The steel industry found many years ago a practical remedy for the stretcher-strain markings produced on automobile sheet on pressing, but this phenomenon has only recently caused trouble with aluminium alloy sheet, since load-bearing car bodies in light metal are a post-war development. The problem was tackled with commendable energy, both on the shop-floor and in the laboratory, and Phillips [25] has described the systematic work by the British Non-Ferrous Metals Research Association which led to not one but several successful methods of eliminating the unsightly blemishes, for which he lists several descriptive appellations.

Although searchlight and other reflectors for illumination are a well-known application of aluminium, the reflectors used in micro-wave radio may not be so familiar. These are as large as 12 feet in diameter, and spun to paraboloid form from a blank made by welding from sheet, since sheets of sufficient size are not available. In an account of this process, Falconer[26] stresses the great precision required in spinning, since the tolerance on the outside edges is about $\pm \frac{1}{16}$ inch. Further, the spinnings have to withstand total wind loadings estimated at about one ton.

Joining

The tremendous improvements made since the war in the joining of aluminium alloys, particularly in large section, are a measure of the acceptance of these materials into many engineering fields, particularly those concerned with structures and with naval architecture. Many methods of making the whole from the parts are available, from riveting (large and small) through gluing to brazing and welding in all its varieties. Binstead[27] has discussed these last three processes, together with a brief reference to soldering, and his paper is useful to the reader requiring an up-to-date general statement on a subject in which advance is rapid and continuous.

It is essential for a full knowledge of welding aluminium that acquaintance be made with the work of the former Welding Research Team at the University of Birmingham, but the published accounts by its members are many and extensive, and Pumphrey[28] has performed a useful service by providing a short summary of the findings, together with some reference to weld porosity and pressure welding. Perhaps the aspect of this work which has aroused least enthusiasm is the development of special welding alloys; it would seem that users prefer to adapt joining methods to existing materials, unless the changes in composition required are relatively minor. Koziarski[29] refers to this matter at the outset of his review of the literature on the weldability of aluminium alloys. He deplores the paucity of papers on aluminium alloy welding, a scarcity which has not impressed itself upon all journal readers—indeed, some may feel the contrary to be the case. However, the article is a useful source of reference, and does reveal that in this particular field European and British workers have certainly contributed much more than their colleagues on the other side of the Atlantic.

There must be few subjects about which a substantial literature has been built up so rapidly as in the case of inert-gas-shielded welding, in its several varieties. The consumable-electrode type rejoices in a number of trade names, and during the year accounts have been published of the Argonaut[30] process in this country, and the Fillerarc[31] in the U.S.A. The English paper is general, with information about the joining of various metals with the Argonaut equipment, but the American article by Tuthill traces the difficulties encountered in the development and design of the Fillerarc welder, and the methods adopted to overcome them. A particular point about the resulting device is that the filler wire is pulled into the gun by rollers, instead of being pushed in by drive rollers near the reel; as a result, wires as thin as 0·030 in. diameter can be used, and only a screwdriver adjustment is necessary to accommodate the range up to 0·065 in. with larger rollers for greater thicknesses.

Wooding[32] might well have entitled his paper on consumable electrode welding: A Treatise for Beginners. It is intended to be educational, and succeeds in its purpose, describing as it does the history of the process, the equipment used, the welding technique, the characteristics of the arc, and gas flow requirements, ending with examples of actual applications. Tomlinson and Young[33] have performed an almost similar service for the process as applied exclusively to aluminium alloys, and they include useful tables showing suitable conditions for butt welds in aluminium-4¼% magnesium plate (NP5/6 in B.S.1477), and for fillet and lap welds on plate in that alloy and sections in aluminium-5% magnesium alloy (NE6 in B.S.1476). Other valuable information includes the results of a series of tensile tests on butt joints in NP5/6, showing weld efficiencies varying from 75 to 100%. Similar data on joint efficiencies are given by Martin, Jacobson and Voldrich[34], who, after extensive experimentation in the argon-shielded welding of thick plate in medium and high strength aluminium alloys (61S, 24S and 75S, roughly equivalent to HP10, HP15 and D.T.D.687), reach the conclusion that the best efficiencies obtainable are, as-welded, 70 to 80% for 61S, 60 to 70% for 24S and 50 to 60% for 75S. Heat-treatment improved the first two figures to 100 and 80–90 respectively, but the last remained unchanged. The authors rather naively conclude that it might be a good idea to try aluminium-magnesium alloys, but note that their use has been limited in the U.S.A. by, amongst other things, the fact that they require special technique in manufacture. In the same journal issue, Gayley[35] and his collaborators have recorded work on the joint efficiencies of consumable-electrode shielded-arc welded plate in the heat-treatable alloy 61ST6 (roughly HP10-WP), and aluminium-magnesium alloys containing respectively 2½%, 3½% and 5% magnesium. These last three alloys were in the H34 condition, strain hardened and stabilised, and they may be compared roughly with alloys NS4, NS5 and NS6, rolled half-hard and then given a low temperature stress relieving treatment. The authors' general conclusion is that the non-heat-treatable alloys showed higher weld efficiencies in the as-welded condition than did the 61S.

The success of inert-gas-shielded welding has led investigators to experiment with the two main gases used, argon and helium, and mixtures of them, to determine their comparative shielding properties. Skolnik and Jones[36] consider that argon has more effect on the properties of the arc in mixtures than helium has, and as long as at least 15% of argon is present the mixture acts more like an argon-arc than a helium-arc. Both Cunningham and Cook[37] and Gibson[38] arrive at the conclusion that the choice of inert gas must depend upon practical considerations, although the former feel that at least 20% of argon must be present in a mixture with helium if its characteristics are to make themselves evident. This is not in complete agreement with the statement of Skolnik and Jones but the discrepancy is not large. All this work is, of course, of theoretical interest only in this country with the present situation as regards availability of helium. Mention should be made of Gibson's rather clever Schlieren photographs demonstrating clearly gas coverage during welding.

Not every fusion-welding problem is best solved by the inert-gas shielded arc, and Maloney[39] has shown that for light-gauge aircraft parts in various aluminium alloys oxy-hydrogen welding is to be preferred, giving higher welding speeds and cheaper operation; distortion is also less of a problem. The jigging and clamping devices described are of interest.

According to Dickinson[40], the use of spot welding for the production of aircraft structural assemblies is rapidly increasing in America. He notes that the famous Liberator bomber contained more than a million structural rivets, and comments that the replacement of these by spot welds would have had a great effect on pay load. Further, spot welding is shown to be a good deal cheaper than riveting. Gardner[41] has described at length spot welding practice in British aircraft construction, paying close attention to design and inspection, and including comparisons of the strength of spot welded assemblies with those joined by other methods. Foretelling the future is always fraught with danger, but Dixon [42] has taken some cautious glances at the perfect machine for resistance welding, basing his prognostications on recent developments. One is impressed to read that the full benefit of these developments can only be achieved by "welding engineers who have a wide knowledge of machine design, electronics, metallurgy and design for welding." Indeed, to quote the executioner in "Saint Joan," it is a "highly skilled mystery."

Miller and Russell[43] have compared the vacuum tightness of argon-arc welded and brazed tubular containers in aluminium-1¼% manganese alloy, and they conclude that both give very satisfactory values. The fixing of chimneys to the corrugated sheet of aluminium Nissen huts presented some problems, but Smith[44] has described how the operation was efficiently carried out by flame brazing.

Two interesting advances[45] in the soldering of aluminium have been reported in 1953, namely, a range of "hard" solders applied by torch heating, and a "soft" solder for use with an iron, by flame heating for making wiped joints in cable sheaths, or by pouring for the joining of conductors. While joints made with the hard solders are claimed to enjoy a corrosion resistance equal to that of the parent metal, most soft-soldered joints must be protected from becoming wet, to be sure of avoiding electrolytic attack.

It is often desirable to join aluminium to other metals, and Miller[46] has collected together the various possible methods, including welding, brazing, soldering and resin bonding. Where the joining of the bare metals presents great difficulties, special measures may be taken. Thus while it is not practicable to braze aluminium to bare steel, if the steel is coated with aluminium a joint can readily be made. Zinc-coated steel may be similarly joined to aluminium. The paper is full of useful practical methods of solving unusual mixed jointing problems.

Constitution

The augmentation of knowledge about the constitution of aluminium alloys necessarily proceeds slowly, because of the painstaking effort involved, and only a little work has reached publication stage during the past year. The aluminium-copper-silicon series is of considerable practical importance, including as it does the most popular of all aluminium casting alloys, and Phillips[47] has reported work during which he has established the composition and melting temperature of the ternary eutectic of aluminium, silicon and $CuAl_2$. The fact that the temperature arrived at, 524° C., is lower than that at which certain aluminium-copper-silicon alloys are sometimes heat-treated, emphasises the slowness of attainment of equilibrium. Similarly, the aluminium-rich apex of the ternary eutectic plane was found to be at 4·9% copper and 1·1% silicon at equilibrium while under conditions of cooling likely to be met with in industrial practice it was at 0·25% copper and 0·25% silicon.

Axon[48] has continued his work on the quaternary system aluminium-copper-magnesium-silicon, which contains, of course, well-known high strength alloys, and reported on the equilibrium relations at 460° C. with a constant silicon content of 0·6% and variable copper and magnesium contents. He distinguishes six phases, namely the aluminium-rich solid solution, silicon, $CuAl_2$, Mg_2Si, Al_2CuMg and $Al_5Cu_2Mg_8Si_6$. Interest has increased in aluminium-tin alloys since their useful bearing properties were studied, and Davies[49] has investigated the possibility of replacing part of the tin by lead—a much cheaper metal. By establishing miscibility limits at 650°, 730° and 800° C., he shows that only a small proportion of lead can be added to aluminium-tin alloys containing up to 30% tin before the composition enters the miscibility gap, so that additions of the element would need to be closely limited.

Properties

The development of distinct new aluminium alloys of practical importance is a rather rare event, and the aluminium-copper-cadmium alloys have therefore attracted a good deal of attention. The workers responsible for this development have added considerably to our knowledge of aluminium-copper alloys, and Polmear and Hardy[50] have reported further work on the age-hardening of binary alloys containing 4% copper and the effect of very small additions of indium and tin. Electron microscopy reveals that these additions cause the precipitated particles to be finer and more numerous, and to occur earlier in the ageing process, thus supporting the authors' previous theory that small proportions of these metals facilitate nucleation.

The importance of the aluminium-magnesium-silicon heat-treatable alloys cannot be over-emphasised; in view of their combination of good strength with high resistance to corrosion, they are the chief structural alloys of aluminium. Recent research has suggested that the intercrystalline weakness sometimes observed with certain compositions can be obviated by additions of manganese or chromium, and Chadwick, Muir and Grainger[51] have confirmed this in an investigation of sheet material with and without such additions. In view of the considerable experience of these workers, one might have wished that they had indicated what, in their opinion, are the optimum compositions and properties for aluminium-magnesium-silicon alloys, taking into account the many factors involved, both as regards ease of production and satisfaction in service.

Creep and its associated phenomena continue to exercise attraction for research workers, and McLean[52] has reported further investigations. Using super-purity aluminium at 200° C., he has established that extension due to grain boundary displacement forms a constant proportion of total displacement, and that the proportion depends upon grain size, as might be expected. Working with commercial-purity aluminium, Grant[53] and his collaborators have shown that at higher temperatures (480° C.) deformation is by slip until the slip band spacing exceeds half the grain size, when it is superseded by grain boundary deformation. With other colleagues, Grant[54] has studied super-purity aluminium in creep at 425° to 625° C., this time with a large grain size. Kink bands are formed, and it is shown that they are associated with bending moments, the plane of kinking bisecting the angle between the slip planes on either side of the boundary of the band. Still further work by Grant and Chang[55] on very coarse-grained super-purity aluminium, commercial-purity aluminium and the aluminium-1¼% manganese alloy, between 200° and 600° C., shows that with a high purity metal it is possible to predict the optimum grain size for creep resistance, since, above this optimum, grain boundary deformation is transmitted to the grain and accommodated by deformation there, while below it boundary sliding has many loci, and is transferred from boundary to boundary.

With alloys, the picture is much less simple, and the existence of an optimum grain size is not demonstrated. Working with very coarse-grained super-purity aluminium only, between 200° and 600° C., the same authors[56] have measured creep across grain boundaries, and present curves relating such creep to that within grains, and over the whole gauge length of the specimen. They conclude that any equation to define a conventional creep curve must be a statistical summation of all the equations representing the various component processes, both within grains and across boundaries. The proportion of boundary sliding varies with temperature, and

at 200° C. this phenomenon is only noticeable in the later stages of creep.

Some confirmation of this last finding comes from the investigation of Betteridge[57] into torsional creep of super-purity aluminium at 200° C. He concludes that the mechanism by which creep strain is produced is the movement of dislocations existing in the material before test, and not associated with viscous movement of the grain boundaries. Supporting evidence is supplied by the fact that very high temperature annealing almost suppresses creep, presumably due to removal of dislocations. Further, single crystals grown from molten metal do not creep at all, but can be induced to do so by introducing a small amount of initial plastic strain.

Studying the sub-crystal structure produced in super-purity aluminium by creep at 200° C. with grain sizes varying from 1 to over 9 grains per millimetre, McLean[58] concludes that the polygonisation theory best fits the observed facts, and checks his results with a model. Gervais, Norton and Grant[59], working with coarse-grained metal at much higher temperatures (approaching the melting point) arrive at a similar conclusion, in that they consider that polygonisation is responsible for forming sub-grain boundaries at the regions delineated by kinking; the authors do not venture any comment as to how their theories might fit finer-grained material at lower temperatures.

In tensile tests on super-purity aluminium at temperatures near the melting point, Pumphrey and Lyons[60] have shown that sudden failure occurs with intercrystalline fracture at a temperature some 4° below the melting point of pure aluminium. They suggest that this might well be due to the crystal boundaries having a slightly lower melting temperature, due not to concentration of impurities there, but to the stress in the boundary producing a depression in the melting point. Calculation of the surface tension in a boundary supports this view, as the value arrived at would produce a melting temperature depression of the order of that observed.

The past year has seen a good deal of work on those properties of aluminium and its alloys which affect working. Aust and Morral[61] have studied earing in commercial purity aluminium, and shown that 45° ears are related to the rolling texture, and 90° ears to the percentage of cubically aligned grains. The position of an intermediate anneal affects the preferred orientation characteristics of cold-rolled sheet. As Van Horn[62] says in the introduction to his American Institute of Metals Lecture, residual stresses in metals operate under a cloak of mystery, as they are only recognisable by their effects, which are so often detrimental. Referring chiefly to aluminium alloys, the author considers the origin of residual stresses and the means of eliminating or reducing them, either thermal, mechanical or a combination of both. An important point emphasised is that distortion on machining is not always due to residual stress in the metal, and other factors should not be forgotten when making a diagnosis.

In addition to the practical work (mentioned above) by the British Non-Ferrous Metals Research Association on the elimination of stretcher-strain marking, research has added to the general knowledge of the effect of various factors on this phenomenon. Hooper[63] has investigated the effect of composition, and shown magnesium in solid solution to be the cause, rather than impurities. He concludes that the markings are associated with atomic rearrangements in a super-saturated solid solution. Phillips[64] and his collaborators have correlated the formation of markings with the stress-strain diagram, and shown that there are two main types, those associated with a large initial yield, and others due to the many subsequent yields associated with strain ageing during the test. In another paper, Phillips[65] studies yield point phenomena in commercial alloys relatively low in magnesium, and shows that the large initial yield is absent, while the extent of strain ageing effects depends on composition and heat-treatment. These effects give rise to a stepped stress-strain curve, and Krupnik and Ford[66] have shown that this is characteristic of aluminium alloys containing copper and magnesium, and that these elements must be present to produce it. The stepping can be avoided only by very low rates of stressing and constant rates of strain.

Another and less drastic defect of the surface of rolled sheet in aluminium and its alloys has been termed "reticulation" by the translator of a paper by Hérenguel[67], the original French word being "resillage." This is evidently a network of minute, very shallow hair cracks, and it is attributed to many factors. Preventive means include scalping of billets, correct roll lubrication, pickling after hot rolling, and, for very high grade material, extrusion prior to rolling.

Williams and Eborall [68] have experimented with super-purity and commercial-purity aluminium, and alloys equivalent to NS3, NS4, HS10 and HS14, to find whether their behaviour on stressing and annealing corresponds with the generally accepted theories regarding the effect of the amount of strain on the grain size after annealing, and the influence of annealing temperature. Only one small departure was observed; with super-purity aluminium, recrystallised after small strains, the final grain size was to some extent dependent on the initial grain size.

All work on grain size and orientation depends upon being able to demonstrate the grain, and two interesting papers on the subject have appeared. Hunter and Robinson[69] have used chemical polishing and the electron microscope to reveal the sub-grain structure in aluminium and certain alloys, and their illustrations are certainly most clear and convincing. Their sample of pure aluminium is stated to be 99·999%, surely one of the highest purities ever attained. By a development of the etch-pit method, Tucker and Murphy[70] have plotted pole figures to indicate the orientation of individual crystals in an aggregate, and they find that their results agree well with those obtained by slower X-ray methods.

Corrosion and Protection

The tendency of all but the noble metals to return to the ores from which they came costs the world an enormous amount of money and effort, either in replacement of corroded structures or in protective measures. Aluminium is one of the most corrosion-resistant of the engineering metals, but, nevertheless, there is still much to learn about its behaviour in many environments.

It was shown many years ago that high-purity aluminium suffers intercrystalline attack in hydrochloric acid or sodium hydroxide, and this has been attributed to the high energy of the grain boundary material. Perryman[71] has investigated the effect of iron content and heat treatment on this corrosion, and he deduces that the preferential attack is due to segregation of iron

in solid solution to the grain boundaries. This finding might be compared with Pumphrey's conclusion about grain boundary melting, mentioned above. Lavigne[72], corroding high-purity metal in hot distilled water, concludes that the metallurgical history of the sample and its texture are highly important; no reference is made to any effect of iron, although the preferential corrosion of grain boundaries is shown to be suppressed by an addition of 0·1% silicon.

Two years is only a short period in which to assess corrosion resistance, which may account for some of the unexpected results reported by Metcalfe[73] in his corrosion tests of fully heat-treated extrusions in alloys HE10 (aluminium-magnesium-silicon) and HE15 (duralumin-type). Thus, the behaviour of the samples, in various atmospheres, and in fresh water and seawater, shows in general less differentiation between the two materials than might have been expected. Unfortunately, no effects on elongation are quoted, but it is stated that there was no evidence of rapid failure due to stress-corrosion, and most of the specimens were exhibiting the reduction in corrosion rate with time embodied in the Champion exponential theory.

It is now well-known that the ageing of cold-worked aluminium-5% magnesium (N6) alloy at very high atmospheric temperatures can result in precipitation of a β-phase, and, if this is concentrated in continuous grain boundary networks, susceptibility to stress corrosion can result, although examples of this happening in service are extremely rare, if they exist at all. Brenner and Metcalfe[74] have assessed the effect of zinc content on this phenomenon, and deduced that 1% of the element aggravates continuous grain boundary precipitation, but up to 0·5% is without effect. Heavily cold worked material, after ageing, is as corrosion resistant as unworked material; 30% is the most dangerous amount of deformation.

Titanium is often referred to as the metal of the future, so that it is interesting to have some indication of its effect in contact with aluminium in a corrosive environment. Ti/Al and Zr/Al couples exposed to marine tidal conditions have shown electrolytic attack of the aluminium[75], so that, on the basis of these items, in any composite structures it will be necessary to take the precaution of insulating aluminium from both metals.

An extensive range of surface finishes is now available for application to aluminium and its alloys, either for protection or decoration, or both, and new ones are constantly being added. In reviewing these finishes, Fenn[76] has stressed the importance of correct preparation of the metal; that this applies to most metals is being increasingly realised. Edwards[77] has confined his account to paint finishes for aluminium, and has provided a useful table assessing the merits and drawbacks of seven classes of paints, so that a choice for any particular combination of circumstances may be made. Opinions have differed in the past as to whether red lead primers are harmful to aluminium alloys in corrosive environments, and Rigg and Skerrey[78] have now shown by exposure tests of 3½ years' duration that such primers can promote attack, especially in marine atmospheres, although not to such an extent as with magnesium-base alloys. Zinc chromate and zinc tetroxychromate are selected as the best primers, although red oxide provided satisfactory protection, particularly in milder environments. Barium chromate was not included in the test.

The title of Armstrong's[79] article is perhaps a little misleading, as it is not a general review of aircraft finishing but an account of the advantages of Alodine pretreatment (Alocrom in this country). That such pretreatments ensure paint adhesion just as well as anodising, is well established, and they are much cheaper; it is good to know that this knowledge is making its impact on those responsible for service aircraft, in some countries at least.

In the past, serious corrosion has been caused by the careless application of unsuitable anti-fouling paints to aluminium alloy hulls, in view of the poisons present—particularly mercury compounds. Kingcome's[80] review of the position is valuable, and he points out the disadvantages of organic poisons otherwise suitable for aluminium; their effect is too short-lived, or they are unpleasant to apply or even poisonous to human beings. The best practice at present is to ensure that the hull is properly painted, using preferably an etch primer and protective paint, and follow with anti-fouling paint, based on rosin and containing cuprous oxide as a poison.

It is only within the last two decades that acceptable methods for the electroplating of aluminium and its alloys have been developed, and a brief but exhaustive review[81] of the methods now available is a useful source of reference. The tinning of aluminium by soldering methods is rather simpler than it was, but Bryan's[82] method by chemical deposition from solutions of stannates is nevertheless interesting, and may have valuable practical applications.

Although the protection of iron and steel by aluminium spraying is now well established, long-term corrosion test results have not hitherto been available. Hudson and Stanners[83] have now published the results of the British Iron and Steel Research Association's extensive corrosion investigations with steel sprayed with zinc and with aluminium, both painted and bare. In marine, rural and industrial atmospheres, but particularly the last, aluminium was shown to provide excellent protection for steel. Indeed, to quote the authors, " . . . aluminium is to be regarded as the most generally serviceable coating of the three " (aluminium, lead and zinc). Further evidence of the interest of the steel industry in the protection of steel by aluminium is given by the valuable paper of Hughes and Moses[84], which both reviews the literature on hot-dip aluminising and describes the authors' own investigations. The account ends with lists of advantages and disadvantages of aluminising as compared with hot-dip galvanising, and it is concluded that each has its own field of application. Certainly, the advantages of aluminium are considerable and no doubt many of the drawbacks will yield to further experimental work.

Applications

As development of the uses of aluminium proceeds, brief articles appear in the technical press recording notable new applications, and together they form a record of achievement. The principal interest is in British work, but it is valuable to compare this with transatlantic accounts, and Edwards[85] has summarised recent American progress in aluminium. His chief references are to improved products, such as larger extrusions and forgings, and tapered sheet, and to important applications such as the S.S. *United States* and the amazing 30-storey Alcoa Building in Pittsburgh.

The *Moraq Mhor*[86], the largest welded aluminium alloy yacht made in this country, is being assembled from

alloy NP5/6 in B.S.1477 by the consumable-electrode argon-shielded arc process, the filler wire being of aluminium-5% magnesium alloy. Also in the marine field, the passenger landing pontoons for the *Orcades* and *Oransay*[87] are examples of the advantages of lightness, both in use and for handling when taken aboard. Those who do not enjoy the venturesome step from the bottom of an accommodation ladder into a swaying launch will bless aluminium alloys!

Road transport still holds pride of place as the industry using most aluminium, and several interesting new vehicles have been described. Among them is an aluminium cattle truck[88] of novel design, with a removable partition which permits use of the vehicle as a double-decker for the transport of calves, pigs or sheep, or as a single decker for large animals. In view of the resistance of suitable aluminium alloys to corrosion by animal waste products, and to mechanical damage from trampling, the cattle truck will outlast several of more conventional design in wood, and is also considerably lighter. The advantages of aluminium construction for tippers working with abrasive and corrosive materials such as sand, ballast and coke are now established, and a recent vehicle for coke breeze[89] is notable for its welded construction, this avoiding mechanical joints which might be less resistant to wear and corrosion than the bulk of the metal. This tipper has already given 18 months' service with little loss of metal thickness, whereas steel bodies require reflooring at least once a year.

Paper bags add appreciably to the cost of cement, and the popularity is growing of delivering the material in bulk to large contracts. A lorry carrying two spherical pressurised aluminium alloy containers[90] is capable of delivering over 8 tons of cement, and elevating it to a height of over 40 ft., where necessary.

The railway field has proved a difficult one in this country for aluminium to enter, despite the success attained in oversea countries. A Canadian railway company has completed six years' experience with all-aluminium box cars, which saved a total of 552 tons in a 100-car train, and is so satisfied with them that it has now taken delivery of a similar fleet of 30- to 70-ton capacity aluminium hopper cars[91], each of which is only threequarters the weight of a similar steel car. They are to be used unpainted.

Bridgewater[92] has set forth the chief factors affecting the efficiency of aluminium alloy structures, emphasising particularly economy in design and correct selection of joining methods. He gives examples of efficient sections and claims that they are 20 to 25% lighter than the present standard (B.S.1161) sections intended for similar duties. The second aluminium alloy bascule bridge[93] in the country was opened in Aberdeen by Her Majesty Queen Elizabeth the Queen Mother last year, and, as with the first at Sunderland, it carries both road and rail traffic. Cold-driven aluminium alloy rivets up to $\frac{7}{8}$ in. diameter were used in the construction.

Modern farming requires equipment that our fathers never dreamt of, and aluminium is helping food production in many ways. The recent attempts by the Ministry of Agriculture and Fisheries to develop a small silo for grain storage includes one type constructed entirely of aluminium[94], and now undergoing service trials.

In establishing television links employing very high frequencies, tests are necessary to determine the best site for each relay station, and portable masts are used. A pair of 200-ft. masts has been constructed in aluminium thus facilitating transport and erection, joining of sections being by galvanised high tensile steel bolts.

The building industry already consumes a considerable quantity of aluminium, and the Aluminium Development Association held during the past year a symposium on building applications, of which accounts will eventually be published. One interesting architectural use has been the extension to the Brotherton Library at Leeds University[96], where aluminium was used for bookstacks, staircases and structural members. The rainwater goods for the Trostre works of the Steel Company of Wales[97] were fabricated from sheet and plate in aluminium—surely a case of penetration into a rival kingdom!

Oil is discovered in regions far from railways or good roads, and transportation of equipment is often a problem. Further, aluminium is highly resistant to corrosion from many crude petroleum products. Several test installations of aluminium pipe for natural gas and oil are being made in America, and welding is being used to provide rapid laying[98].

Few references appear in the metallurgical press to aluminium foil, despite the fact that output in this country exceeds 12,000 tons per annum. Its uses are mentioned, amongst other aluminium applications, in an article on packaging in 1953[99], inspired by the holding of a successful exhibition on this subject in London.

Lastly, two examples of aluminium's versatility. Gardam[100] has described how less than 1% of aluminium in sterling silver prevents the occurrence of "fire stain," that disfiguring discoloration which is caused by overheating in working of the metal. The book by Case and Van Horn [101] on aluminium in iron and steel shows that it has two main functions—as a deoxidiser and as an alloying addition. Its effects on many properties of steel are described.

Standards

Constant effort is beginning to have its reward, and the aluminium alloy nomenclature in B.S.1470–1477 is being increasingly used by the authors of papers and articles, as by the engineering industry, to the exclusion of the hotch-potch of commercial names and mis-applied aircraft designations previously so common. The year has seen the issue of no important new standards for alloys, as a period of consolidation is now current, but the time is approaching when B.S.1470–1477 will require revision in the light of experience.

In the field of applications, British Standards have been published for aluminium brazing alloys[102], large rivets[103] and ladders, steps and trestles[104] for building and civil engineering use. In the general revision of the British Standard Packaging Code, Section 10[105], has been revised and covers aluminium containers generally, while the dimensions of collapsible tubes[106] have also been standardised.

An important reminder has been issued by the Light Metal Founders' Association[107]. Those effects of keen industrial competition which are beneficial are many, but they do not include the lowering of standards of quality, and it is good to see this body urging upon users the benefits of adhering to established standards, and the pitfalls in the way of those who, for a trifling reduction in first cost, abandon this protection. Although industry becomes yearly better educated about quality standards, there are still failures which show that propaganda such as the above article is not yet out of date.

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Co-operation in Research

Illustrations from the Iron and Steel Industry

For his Presidential Address to The Sheffield Metallurgical Association, Mr. F. H. Saniter took as his subject the post-war expansion of The United Steel Companies' Research and Development Department. In this abridged account of the Address, attention is mainly focused on a number of examples illustrating the value of co-operation in plant scale experimentation.

AT the recent Annual General Meeting of The Sheffield Metallurgical Association, the new President, Mr. F. H. Saniter, devoted his Presidential Address to an account of the post-war expansion of the United Steel Companies' Research and Development Department, of which he is Director. Mr. Saniter referred to his close association with the late Dr. Thomas Swinden who, with Dr. Hatfield and Mr. Dickinson, had laid so well the foundations of the Association in 1917. Dr. Swinden had spent the last twelve years of his life, from 1932 to 1944, in building up the organisation of which he, Mr. Saniter, was now the Head. The President then outlined the growth of the Department from a staff of 73 to one of 190 in the last 10 years, the main expansion being the formation of a group of development engineers to specialise in iron and steel works plant, and mineral and fuel sections to cover all raw materials used in iron and steel making. Details were given of the structure of the organisation and its relationship with the numerous branches of the Company, through a system of committees composed of senior members of the Department and managerial and technical staffs at the branches. In this way the Department was brought into formal contact with works problems, but more important were the friendly informal relationships which arose in the course of the work. In addition, close co-operation existed with the Research Associations and with other firms in the industry, thus promoting the free flow of information on technical matters*.

The organisation now embraced several branches of science and technology, and thus enabled many complex problems to be tackled by team work, each man contributing experience and knowledge in his own specialised field. In particular, this facilitated plant scale experimentation, a field inadequately covered in the past, which could be made to yield a rich harvest. The speaker then discussed four examples of such work.

Faster-Melting Furnaces

The first example concerned the development of faster-melting open hearth furnaces in the Templeborough melting shop, emphasis being laid on design, instrumentation and the materials of construction. The Templeborough furnace trials, fully recorded in Iron and Steel Institute Report No. 37, were a joint operation by the British Coal Utilisation Research Association, the Templeborough melting shop staff, and the Research and Development Department. In the laboratory, a technique for determining the flow patterns in open hearth furnaces using $\frac{1}{24}$th scale hydraulic models, made from Perspex, was developed. Ideas arising from discussion with the melting shop staff were put to test in the laboratory and, as a result, quickly translated into reality in the form of " K " furnace at Templeborough, one of the first single-uptake oil-fired furnaces to be tried in this country, a special feature being the sloping end wall, designed to give a flow pattern beneficial to the life of the refractories. The design proved admirable and, since it started rather in advance of where the Company's more conventional furnaces left off, it was felt that, by observation of its service performance, and suitable modification from time to time—a normal process of evolution—there were good prospects of its further improvement.

The open hearth furnace had also been the object of practical work on the development of improved refractories, and a most stimulating competitive situation had been created by the introduction of " all-basic " construction, on the one hand, and the judicious use of Silcrete, an improved silica refractory, on the other. It was interesting to record that, since 1948, when the first " all-basic " furnace was put into commission at Templeborough, the average life of a silica roof had increased from 125 casts, at a rate of 13 casts per week, to 200 casts, at a rate of 14 casts per week, thus appreciably raising the standard against which the performance of the all-basic furnace must be judged. There were now two all-basic furnaces in the shop and their performance, as regards both output rate and refractory cost, was being carefully watched.

The detailed study of the performance of open hearth furnaces had led to the use of instruments and measuring devices of various kinds necessary for the ascertainment of the required information. Such experimental use of instruments had had a decided influence towards the increased instrumentation of furnaces as an aid to routine operation.

Oil-Fired Preheating for Arc Furnaces

Turning now to another branch of the Company, Samuel Fox, Mr. Saniter said that attention had been paid to the development of an idea, which emanated from the manager of the electric steel plant, whereby the charge of an electric arc furnace would be pre-heated or pre-melted under an oil-fired hood, after being placed in the body of the furnace, the body being transferred in due course to its normal position under the electrodes for completion of the heat (Fig. 1). By this means, it was suggested, not only would the cost of electricity and electrodes per ton of steel be reduced to one-third, but also it would mean that, if oil pre-melting were established as a regular practice, the electrical equipment normally provided for a 10-ton cold-melt furnace would be capable of refining a 30-ton charge.

It was one thing for a melting shop manager to have an interesting idea, but quite another for him to develop it to the stage of practical application, and for this

* Fuller information concerning this aspect of The United Steel Companies' Research and Development Department can be found in *Metallurgia*, August, 1952, pp. 89–93.

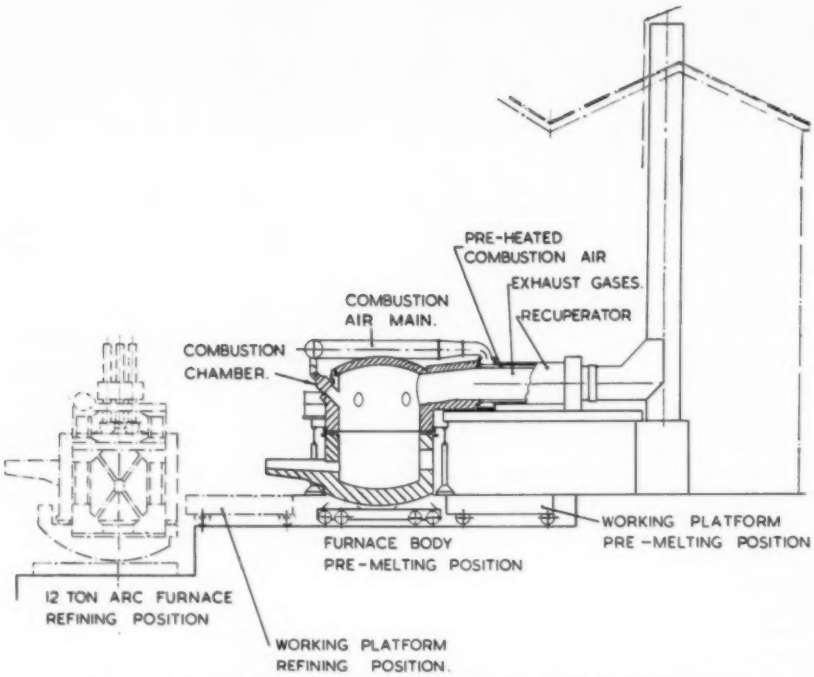


Fig. 1.—Pre-melting of electric arc furnace charge under intense combustion hood.

purpose the resources of the Research and Development Department were brought into play. For some time, thought had been given to intense combustion, and the possibility of burning much larger quantities of oil per unit of combustion space, so that when the pre-melter idea was suggested it aroused considerable interest and enthusiasm. First, the shape of the combustion space had to be considered, and the expected flow pattern arising from various arrangements of burners and exit flues determined. The next stage was to build a $\frac{1}{8}$th scale hot model to determine whether ferrous metal could, in fact, be brought to melting temperature. This led to special consideration of burners and, with some initial help from Joseph Lucas, Ltd., a burner, based on the principles of the jet engine combustion chamber, was evolved which gave a phenomenal heat release. As the next step, thanks to the courage of the Fox management, a full scale pre-melting hood was designed and installed in the electric steel plant at Stocksbridge in conjunction with a 10-ton arc furnace. The unit embodied six of the special burners, or jet-cans, each capable of burning 40 gallons of oil per hour, pre-heated air being supplied from a recuperator installed in the waste gas system. Oil could be burnt under stoichiometric conditions to provide 82,000 B.T.U./hr./cu. ft. of furnace volume, which was eight times the equivalent rate of heat release in an average open hearth furnace.

As the trials of the pilot plant, which were designed to determine both the practicability and the economics of the process, were still in progress, it was not possible to quote results, beyond saying that oil had been burnt for prolonged periods at the rate of 240 gal./hr., and the practicability of melting by the method had been established. Whether the economics of the operation proved to be attractive or not remained to be seen, but in any event a piece of valuable team work, involving both Fox and R. & D.D. personnel, had been accomplished, and a great deal of valuable information and experience gained which was already being applied in other directions.

Continuous Casting of Billets

Another plant scale operation for which the Department had a technical responsibility was the Rossi continuous casting machine, which had been installed experimentally at the Barrow steelworks (Figs. 2 and 3). It was desired to produce 80,000 to 100,000 tons of billets per annum from the existing open hearth furnaces, without recourse to the billet mill, which was not only obsolete but quite uneconomic to operate on the basis of such a small annual tonnage. The billets were required to feed the existing re-rolling mills, the major part of the demand being for 2 in. square section.

In order to facilitate the experimental work, which was being supervised by a member of the departmental staff seconded to Barrow for that purpose, a 5-ton electric arc furnace had been installed adjacent to the pilot casting machine, so that small quantities of metal could be supplied readily from time to time without interfering with the production of the open hearth shop.

The casting of billets as small as 2 in. square on a production basis was novel, to say the least of it, and presented unusual difficulties due to the high speed of withdrawal necessary to achieve a reasonable production rate, not to mention maintenance of the metal at a sufficiently high temperature for the duration of the operation. Indeed, the second of these problems was the first which had to be tackled, and it was solved largely by the use of the jet cans referred to earlier for pre-heating the ladle and maintaining the temperature of the metal during casting. It was now possible to tap at the temperature which would normally be employed in open hearth practice, and to maintain a sufficiently high temperature in the ladle until casting was complete.

The target set for the rate of casting was 5 tons/hr. which was equivalent to about 200 in./min. This in itself set a problem, since the $\frac{7}{16}$ in. diameter nozzle suitable for such a rate of pouring was very prone to freeze up, if the tundish and nozzle were not adequately insulated and pre-heated before casting started. Casting into a 2-in. square mould also necessitated a clean stream of metal, and the design of a suitable nozzle to achieve this required a good deal of thought and experiment.

The development of this technique to the point where a 5-ton ladle of metal could be cast into 2 in. square billet in an hour, with absolute regularity, had yet to be reached, but good progress had been made. They had, on numerous occasions, achieved this rate of casting, a feat which many would have thought quite impossible

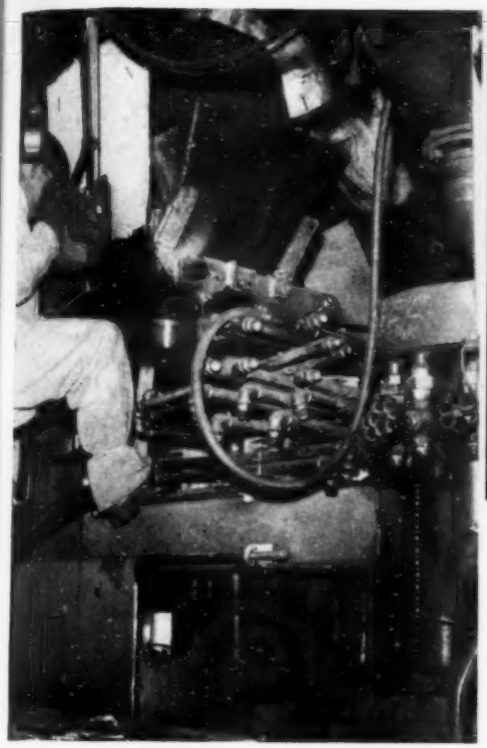


Fig. 2 (left)—Pilot plant for continuous casting of steel billets.
Fig. 3 (above)—The stream of metal entering the mould in the continuous casting plant.

a year ago. There were still many things to work out, not the least of which was how to dispose of a 50-ton open hearth cast in a reasonable period of time.

The problems arising in such a pioneering effort were legion, and many sections of the Department and the Barrow works had contributed to their solution. There were still many to be solved, however, as for example, a method of indicating the level of the metal in the mould, and linking it to automatic control of the withdrawal mechanism.

Sinter Plant Experiments

The final example related to an extensive investigation into the factors controlling the rate of sinter production on the four Dwight-Lloyd sinter strands at the Appleby-Frodingham works. Again, it was a good case of collaboration, the team which worked on the plant for three months being composed of R. & D.D. and Appleby-Frodingham personnel, with a B.I.S.R.A. man, who had a useful background of sinter plant experience, as team leader.

The four strands had a nominal design capacity of 24,000 tons of sinter per week, but in view of the nature of the Appleby-Frodingham ore, and the need to return a substantial proportion of the sinter fines to the feed, they had been derated to 18,000 tons/week. At the time the investigation was undertaken, output was running at a considerably smaller figure and something had to be done about it. An added impetus was derived from the fact that a further four sinter machines were about to be ordered, and it was highly desirable that knowledge of the process, particularly in relation to Appleby-Frodingham ore, should be improved so that the findings could be taken into account in the design of the new plant.

The process consisted of a travelling grate on to which a layer of ore fines, mixed with about 5–7% of coke breeze, was fed to a depth of 12–14 in. (Fig. 4). The belt passed beneath a gas-fired hood which ignited the surface layer, ignition being sustained by air drawn through the bed by means of a powerful fan.

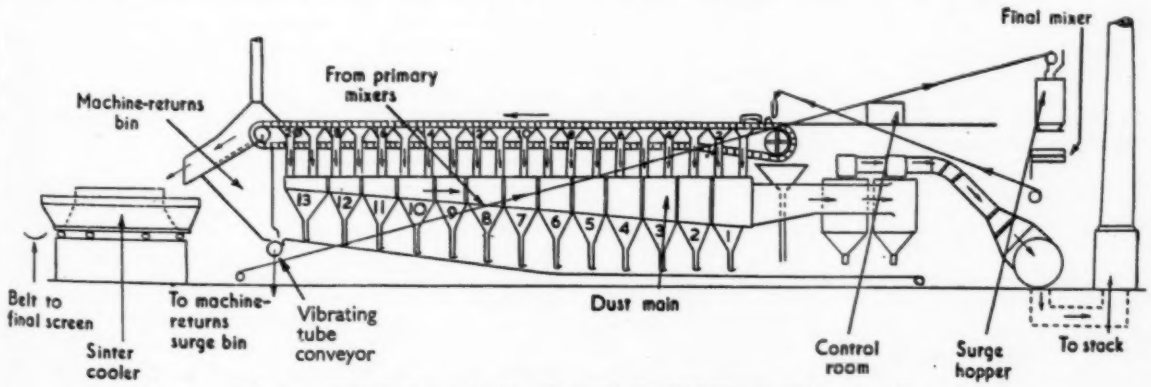


Fig. 4.—Diagrammatic section through Dwight-Lloyd sinter strand.

The plant was instrumented, and careful assessments of its operation made under normal conditions, and with modifications such as altered bed height and strand speed. Analyses of the test data showed that the sinter make was mainly controlled by the amount of air drawn through the bed. This focused attention on fan efficiency, air leaks, pressure drops through the system and, most important, the permeability of the bed itself. Means were devised for obtaining a continuous record of bed permeability with the plant in operation, and this enabled the effect of changes in the mixing of the sinter feed to be quickly assessed.

In all, the team carried out 39 trials which were done on alternate days, the results being tabulated and analysed on the intervening days as the trials proceeded. In this way, the picture was kept clearly before all concerned, and as progress was made so was enthusiasm sustained. Apart from the plant scale experiments themselves, valuable supporting work was done in the laboratories of the sponsoring organisations with a praiseworthy celerity. The mass of data arising from this project, which was nicknamed the 39 steps, had been admirably condensed into some 50 pages of the October issue of the Iron and Steel Institute Journal.

The most immediate benefit of the work was that it enabled the plant operators so to control the mix (and hence the permeability of the bed) that an output of 25,000 tons/week of sinter was quickly achieved. This figure had since risen to 30,000 tons a week. No less important was the provision of basic data from which the optimum relationship between bed depth, strand length and fan horse power for any given set of conditions could be calculated. This was promptly applied to the design of the four new strands which would be much better balanced units than the existing ones. They would come into commission shortly, almost exactly three years from the commencement of the trials.

A supplementary investigation, undertaken at the same time, was concerned with the problem of sinter cooling, it having been proved beyond doubt that it was uneconomic to attempt to do this on the strand. Design data was provided on which a new type of forced draught rotating hearth cooler had been based and coolers of this type would serve the new machines.

More Molybdenum

As a result of the expansion programme just completed, the capacity of the Climax Molybdenum Co. has increased to an anticipated output in 1954 of 42·5 million pounds. The Company's molybdenum mine at Climax, Colorado, is now the largest underground mine in North America, and the Climax expansion has raised free world capacity by two-thirds since Korea. This capacity is now more than 65 million pounds, or well over twice as much as the total annual molybdenum consumption of the free world in the four years between World War II and Korea. The American Government lifted domestic controls from molybdenum on June 30th, 1953, and on January 14th last ended the quota system with which it had controlled the amount of metal shipped to Western Europe and the rest of the free world. Any consumer in these areas who obtains an export licence can now purchase all the molybdenum he wants.

Kent Alloys Acquired

We are informed that Birfield Industries, Ltd. have further extended their industrial activities by acquiring the whole of the shares of Kent Alloys Ltd. of Rochester, which company manufactures high grade light alloys, with special reference to those requiring radiological control for the aircraft industry, as well as grey iron castings. Kent Alloys also have extensive machine shop and assembly facilities. The new Directorate is Mr. H. E. Hill (Chairman), Mr. V. C. Hanson and Mr. C. E. Lovelace (Resident Directors) and Mr. G. T. Hyslop, Mr. D. L. Roome and Mr. W. Smithson of The Phosphor Bronze Co. Ltd., Birmingham, which company is also a subsidiary of Birfield Industries Ltd.

Platinum Price

Increased output from the Rustenburg mines in South Africa, made it possible, in July, 1950, for Johnson, Matthey & Co., Ltd., to stabilise the price of platinum in the United Kingdom at £27 per ounce troy. This policy has been effective in making supplies available to users at a steady price for the last three and a half years. During that time, however, the level of working costs has risen appreciably, and it is necessary now to make some adjustment in price. From February 1st, therefore, the price of platinum has been increased by £3 to £30 per ounce troy. This adjustment does not mean any departure from the company's policy of making platinum available at as low and stable a price as possible.

Advisory Service for Lead Pipe Industry

As has been announced in connection with the initiation of an Advisory Service for Electroplaters, the British Non-Ferrous Metals Research Association, taking advantage of £15,000 allocated to it by H.M. Treasury from the sterling counterpart funds created to balance the dollar aid received by this country under the U.S.A. Mutual Security Act, 1952, is expanding the services it offers to industry in the application of research results and other scientific knowledge in production practice. Part of this expansion will be directed towards the provision of certain new technical services for the Lead Pipe Industry.

Very largely as a result of research sponsored by the Lead Sheet and Pipe Manufacturers' Federation, and carried out by The British Non-Ferrous Metals Research Association over a number of years, knowledge of the mechanical properties of lead and the effects of extrusion conditions thereon has been accumulated. This body of knowledge now serves to show the way to improving the efficiency of the use of lead in domestic water distribution pipes.

The manufacture of pipes of improved quality for pressure services would require close control of the metallurgical condition of the lead and of the manufacturing process. With the requisite degree of control of these factors, the optimum mechanical properties of the material could be realised, and a superior product possessing both technical and economic advantages obtained.

The Association is in a position to help the Lead Pipe Industry with advice on methods of controlling the properties of its products, so enabling it to increase its productivity.

NEWS AND ANNOUNCEMENTS

Conference on Mechanical Effects of Dislocations in Crystals

ORGANISED by the Department of Metallurgy at the University of Birmingham, a Conference on Mechanical Effects of Dislocations in Crystals will be held on 19th and 20th July, 1954. The Conference will be concerned with recent advances in our knowledge of the effects of dislocations on the mechanical properties of metals. It will thus be complementary to the Bristol Conference to be held between the 13th and 16th July, which will consider chemical aspects of dislocations in crystals. Both these conferences follow the Meeting of the International Union of Physics, and it is hoped to attract a wide attendance. Contributions have been invited from Dr. J. D. Eshelby, Dr. J. H. Holloman, Prof. J. S. Koehler, Prof. R. Maddin, Prof. N. F. Mott, Dr. W. T. Read, Dr. J. C. Fisher, Dr. M. A. Jaswon, Dr. Doris Kuhlmann-Wilsdorf, Prof. E. W. Parker and Dr. T. Suzuki. The Conference will open at 10-30 a.m. on Monday, the 19th July, and will close on the afternoon of Tuesday, the 20th July, in time for any who wish to do so to travel to Paris for the Crystallography Congress opening there on the 21st July. The Conference is open to any scientist interested in this field, up to the limit of seating accommodation (200). Some 50 single and 25 double rooms will be reserved in a University Hall of Residence opposite the University, for the nights of the 18th, 19th and 20th July, the inclusive charge being about 25s. per day. Further particulars can be obtained from the Conference Secretary, Department of Metallurgy, University of Birmingham, Edgbaston, Birmingham, 15.

Corrosion and Packaging Lectures

IN co-operation with the Printing, Packaging and Allied Trades' Research Association and the Institute of Packaging, a course of five lectures on corrosion and packaging has been arranged by the Department of Applied Chemistry, Northampton Polytechnic. They will be held at 7 p.m. on successive Wednesday evenings, commencing 10th March, 1954. The topics to be dealt with include: introduction and general principles of corrosion; general principles of packaging of corrodible articles; prevention of corrosion; barriers and desiccated packs; and selection of the packaging method; the respective lecturers being Dr. W. H. J. Vernon, Mr. J. J. Ferriggi, Dr. D. Clayton, Mr. D. J. Evans and Mr. F. A. Paine. The fee for the course is £1 1s. and further particulars can be obtained from the Principal, Northampton Polytechnic, St. John Street, London, E.C.1.

Course on Reaction Rates

THE Department of Extra-Mural Studies of the University of Liverpool, in collaboration with the Department of Metallurgy, has organised a two-day post-graduate course on "Reaction Rates in Metallic Systems." This short course is designed to present a general outline of the theory of the subject, and a knowledge of physical metallurgy to ordinary degree or equivalent standard will be assumed. Whilst the use of proofs requiring a knowledge of advanced mathematics will be avoided, a working knowledge of elementary mathematics and thermodynamics will add greatly to the interest and benefit of the course. The eight lectures, which will be given by Dr. W. S. Owen (Lecturer in Metallurgy in the University), will cover the following topics: brief consideration of the relevant theory in statistical mechanics and thermodynamics; the concept of activation energy and the theory of absolute reaction rate; the general theory of homogeneous nucleation; further consideration of nucleation theory; growth of precipitates and overall rates for precipitation processes; applications of the theory to precipitation from solid solutions, martensitic reactions, diffusion, stress-strain phenomena, etc.; general discussion. The course will be held in the University (Main Building) on 23rd and 24th March, 1954, and the fee for the course is £2 2s. Enquiries should be made to the Director of Extra-Mural Studies, University of Liverpool, 9, Abercromby Square, Liverpool, 7.

Iron and Steel Scrap

AFTER consulting the Iron and Steel Board, the Minister of Supply (Mr. Duncan Sandys) has made an order affecting the acquisition and certain prices of iron and steel scrap. The Order limits the need for a licence to acquire iron and steel scrap to persons engaged in: (*a*) the smelting of iron ore in a blast furnace with other metalliferous materials or the production of iron by any other process; (*b*) the production of steel by any process; or (*c*) the casting of iron or steel by any process. The Order also removes tungsten steel scrap from price control, and amends the instruction for calculating maximum prices where delivery is effected otherwise than by the British Transport Commission or Licensed Road Hauliers.

The Order, the Iron and Steel Scrap (Amendment No. 2) Order, 1954, S.I. 1954 No. 50, came into operation on January 21st, 1954, and can be obtained from H.M. Stationery Office.

New Welding Publication

WE are advised by the British Welding Research Association that most of its published work is now appearing in the new monthly *British Welding Journal* which is being published by the Institute of Welding. The Association's bi-monthly *Welding Research* has, therefore, been discontinued as from the December, 1953, issue. The new publication will also incorporate the *Transactions of the Institute of Welding*.

Dorman Long Order for Metrovick

As a result of a further step in the new expansion programme of the steel industry, Metropolitan-Vickers Electrical Co., Ltd., has recently received an order for the electrical equipment of a 40-in. blooming mill at the Cleveland Works of Dorman Long & Co., Ltd. The mill will have a 5,000 h.p. twin-motor drive, one motor being coupled directly to the top mill roll and the other to the bottom roll. This arrangement dispenses with the need for the conventional mill pinion gear box. The control scheme has been specially developed to

ensure rapid starting and reversal of the main motors, and employs metadyne high response exciters. Provision is made for automatic load limiting, individual speed adjustment of the motors, and voltage compensation on the generators.

Personal News

Mr. L. H. Short has been appointed General Export Manager of The English Electric Co. Ltd., in succession to Mr. H. S. Aspinall, who retired at the end of last year after holding the appointment from 1937. Mr. Aspinall will remain a Director of The English Electric Export and Trading Company, and will continue to serve the Company on special duties and projects in connection with its export affairs.

Mr. G. Lloyd Jones has been appointed Manager of the B.T.H. Cardiff District Office, in succession to Mr. A. F. MacCarthy who has retired.

Mr. J. E. C. Bailey, C.B.E., Chairman and Managing Director of Baird and Tatlock (London) Ltd., and Hopkin and Williams, Ltd., is at present in Africa making a tour of organisations set up under Scientific Exports (Great Britain) Ltd., and also visiting customers in these territories. His six weeks' tour includes Johannesburg, Durban, Salisbury, Lusika, Nairobi, Kampala, Entebee and Jinja.

Dr. N. Booth has been appointed General Manager, Research and Development, of The British Oxygen Co. Ltd., in succession to Dr. P. H. Sykes, whose appointment to the Company's Board was announced recently.

Mr. A. Black, Works Manager of William Jessop and Sons, Ltd., Sheffield, for the past six years, has joined the Cleveland Steel and Iron Co. Ltd., in a similar capacity.

Mr. A. Jones, M.P., has been appointed Economic Director of the British Iron and Steel Federation. Mr. Jones has been employed by B.I.S.F. since 1949, and has been Assistant Economic Director since 1950.

The Honorary Degree of D.Sc., will be conferred upon Dr. F. Meyer, Chairman of the South African Iron and Steel Industrial Corporation Ltd. (ISCOR), at a graduation ceremony at Pretoria University in April.

Mr. M. Littmann, formerly Managing Director of Metro-Cutanit Ltd., is now a Consultant at 4, Bryanston House, Dorset Street, London, W.1.

Mr. W. G. Thomas, has been elected a Director of Radiovisor Parent, Ltd. Mr. Thomas is also Managing Director of Bailey Meters and Controls, Ltd., Chairman of The British Industrial Measuring and Control Apparatus Manufacturers' Association, and a Director of The Sutherland Permanent Building Society.

Mr. W. F. Randall, Director of The Telegraph Construction and Maintenance Co. Ltd., is at present on a two months' visit to the Company's branches and representatives in Karachi, Bombay, Singapore, Australia and New Zealand, including a visit to the Company's estate in Malaya, the Selborne Plantation. Mr. Randall is chiefly concerned in promoting increased sales of Telcon metals in these territories.

The Directors of Baird and Tatlock (London) Ltd., and Hopkin and Williams, Ltd., recently gave a Dinner in honour of their Chief Chemist, Mr. W. C. Johnson, to mark the award to him of the M.B.E. in the New Year Honours List.

The President of the Board of Trade has appointed Mr. Maynard Jenour, T.D., J.P., to be a Director and Vice-Chairman of the Board of Wales and Monmouthshire Industrial Estates, Ltd., as from 28th January, 1954.

Mr. Leon Bailly, for many years a Director of the International Furnace Equipment Co. Ltd., of Aldridge, resigned from that position at the end of 1953 owing to increasing commitments on the Continent. He will in future operate mainly in France and Belgium in conjunction with "Le Gaz Intégral" of Paris, with whom the International Furnace Equipment Co. Ltd., is closely associated.

Mr. B. A. Robinson, who has been with the Cambridge Instrument Co. Ltd., for 41 years, and has been their District Representative for 32 years in the Newcastle-upon-Tyne area, has now retired. He is succeeded as District Representative by his son, Mr. W. E. Robinson.

Obituary

Mr. E. J. Fox

We regret to record the death, on January 18th, at the age of 80, of Mr. E. J. Fox, former Managing Director of The Stanton Ironworks Co. Ltd., one-time chairman of Davy and United Engineering Co. Ltd., and one of the foremost figures of the British iron and steel industry between the wars. Mr. Fox, who was also a director of Stewarts and Lloyds, Ltd. and Crompton Parkinson, Ltd., was educated at Rugby. He spent the first twenty years of his business career in the electrical industry, but in 1917, on joining the Stanton Ironworks Co. Ltd., as managing director, transferred his attentions to the industry in which his reputation was to be made, that of iron and steel.

During the period of his managing directorship at Stanton, which covered the years 1917–1942, the company was developed into one of the largest manufacturers of cast-iron pipes in Europe. Under his guidance the centrifugal casting process, which completely revolutionised pipe manufacture, was largely developed at Stanton and brought to commercial perfection in Great Britain. The donation which Mr. Fox gave in 1936 to the Institute of British Foundrymen, to provide the annual award of the E. J. Fox Medal for outstanding work in the field of foundry metallurgy, commemorated the success of this process.

In 1931, Mr. Fox also assumed the chairmanship of Davy and United Engineering Co. Ltd., of Sheffield. He took over the direction of this old-established company at one of the most difficult periods of its history. The subsequent notable prosperity which the company has enjoyed, and its development into the largest builder of rolling mill and forging press plant in Europe, is attributable in no small degree to the wisdom, foresight and energy which Mr. Fox brought to his task. He relinquished the chairmanship in 1944 and retired from the board of Davy-United in October, 1953.

Probably some of his most lasting work, however, was done in the field of labour relations. His establishment in 1921 of works committees at Stanton was a pioneering development in employee-employer relationships which has served as a model for much subsequent work in this field.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

New Flow Meter

THE latest Kent mercurial flow meter, the KU, represents the first step in a new policy of standardisation which will embrace the " presentation " mechanism of a new range of meters to be known as the Commander class, i.e., the case and front mechanism, including recording, integrating, indicating and automatic control systems. The user will then be able to fit additional "presentation" features to a meter, or to interchange parts between one meter and another, and thus reduce the number of spares carried. Pre-calibration of relevant parts increases this flexibility by allowing the user to assemble a variety of instruments from standard units should he so desire, as well as alter ranges easily. The uniformity of appearance of the whole Commander class, especially on panels, will please many people.

The KU meter is available for the recording, indication, integration, and automatic control of the flow of oil, water, air, gas, steam and most industrial liquids ; and it works in conjunction with a Venturi tube, Dall tube or orifice in the fluid pipeline. Its interchangeable mercury chambers are steel forgings, designed to receive maximum differential pressures of 25, 50, 100, 200, 400 or 600 inches of water (air-on-mercury basis). The new-design float (in the downstream chamber), subject of a patent application, rises for an increase in differential pressure. The extension of the U-tube is thus downwards and the easily separable control head is a standard unit. Only a new upstream mercury chamber and U-tube are required for a range change, which can be made on site. An adjustable throttle valve in the downstream leg of the U-tube damps out the effect of a pulsating-flow characteristic. Streamlined over-load valves provide a safeguard against loss of mercury on excess or reverse loads. The control head includes two mild-steel forgings specially designed to reduce the number of joints to a minimum.

The movement of the float is carried to the " presentation " mechanism through a grease-packed, hat-leather-type gland, designed to reduce friction to a minimum ; a jewel thrust bearing is provided for the gland spindle. The " presentation " mechanism can accommodate up to two pens and a pointer, as illustrated, the second pen being for pressure measurement from a pre-calibrated Bourdon tube unit mounted in the case.

The integrator, electrically or mechanically driven, is a separate pre-calibrated unit. The entirely new electrical type has a large five-figure cyclometer counter, a range of up to 10 : 1, a minimum step error, and is unaffected by vibration. The mechanical type uses a direct linkage to operate a tractorwheel frame instead of the conventional cam greatly reducing the power absorption from the instrument.

The principle of measurement on which this meter is based is a well-established one, but it is claimed that the degree of practical perfection to which that principle has been carried represents a definite advance.

George Kent Ltd., Luton.

Alumintex

FOLLOWING the introduction of Cowanite, a zinc and latex rust inhibitor, The Adelaide Engineering Co. have now developed Alumintex, which is comprised of aluminium and latex together with other carrying agents. It can be applied direct to all metals, wood, cement, asbestos, stone and slate, and, although the surface should be free of grease and loose rust and paint, adherent rust, mill-scale and paint provide a suitable base for its application. Alumintex is claimed to last much longer than ordinary aluminium paint, and to be repellent to dry rot, wood worm and fungus.

The Adelaide Engineering Co., Waterloo Road, Liverpool, 22.

Tubemakers' Slide Rule

THE normal manufacture of seamless metal tubes is essentially a problem of reducing the cross-sectional area of the material until the required diameter, thickness and length are obtained. Numerous hot and cold processes are employed, but whatever the process there are certain common factors that must be studied. These include outside diameters, bores, thicknesses, cross-sectional areas, percentage reduction of all these, and also lengths, elongations and weights.

Tubemaking calculations can be made in many ways, depending on individual skill and including the use of tables, charts and ordinary slide rule methods. Tables and charts can never cover all sizes of tubes and ordinary slide rules call for some mathematical skill in their use. The Department of Development and Research of Tube Investments, Ltd. has, therefore, designed a special slide rule for facilitating calculations concerning tubes. No previous knowledge of slide rule operation is necessary —all the procedures being detailed in an explanatory manual ; the rule is, in fact, already being used in many T.I. works, not only by process planners, but by operators on the shop floor.

The rule is intended primarily to provide a better method of process planning, but it is also valuable in other departments, such as those concerned with plant design, estimating, sales, export, despatch, and invoicing. In testing departments, where speed and accuracy of calculation are of such vital importance, the rule is particularly useful. Other applications will be found in those industries concerned with deep drawing, or with the rolling and drawing of bars, wire, and metal sections.

Norton "G" Bond Grinding Wheels

NORTON GRINDING WHEEL CO., LTD., have now released in this country, their newest development, "G" Bond Vitrified Wheels for precision and semi-precision grinding. Extensive field tests have shown that "G" Bond wheels have the capacity to cut cooler and more freely than wheels with existing types of bond. This is attributed to their "breaking down" at just the right time in the grinding cycle, in such a way that the abrasive grains that have lost their sharpness are released without disturbing the adjacent sharp or unused grains. It is this same characteristic that helps to give longer wheel life. Similarly, the manner in which the wheel face retains only sharp particles of abrasives makes it possible to take heavier cuts and obtain proportionately faster stock removal. So far as form grinding is concerned, further tests proved not only that "G" Bond wheels hold their form longer, but, also, that they are much easier to "true" or form either with diamond tools or crushing rollers.

Summing up, tests already carried out with "G" Bond Norton Wheels have proved that they will:

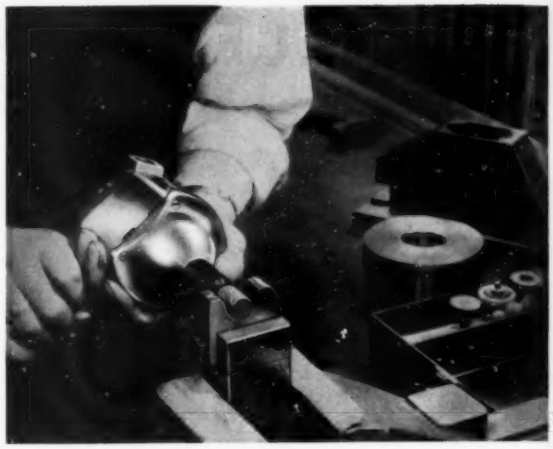
1. Cut cooler.
2. Remove material faster.
3. Produce a better finish.
4. Give longer life and more pieces per dressing.
5. Hold shape and corners better.
6. Dress more easily either with diamond tools or crushing rollers.

"G" Bond wheels can be supplied in any of the Norton Aluminous Oxide abrasives, viz., Alundum, 19 Alundum, 38 Alundum or 32 Alundum, and will give improved results on practically all precision and semi-precision types of work, including cylindrical, centreless, thread and other types of form grinding. For the majority of standard applications "G" Bond wheels are available ex-stock.

Norton Grinding Wheel Co., Ltd., Bridge Road East, Welwyn Garden City, Herts.

New Die Grinder Kit by Wolf Electric Tools

THE new die grinder kit (type DG1), introduced by Wolf Electric Tools Ltd., is a handy versatile tool which will undertake a great variety of jobs in every tool room, machine shop and maintenance department. The powerful driving unit which possesses abundant speed and power, has a capacity for grinding wheels up to $1\frac{5}{8}$ in. dia. $\times$ $\frac{5}{16}$ in., and has a speed (running light) of 16,000 r.p.m. The input on full load is 270 watts, and the nett weight is 5 lb. Although primarily intended as a portable tool, it may with advantage be mounted in a bench clamp stand for stationary use. High tensile aluminium alloy is selected for the motor frame, which is finished in attractive polychromatic stove enamel.



Dust-sealed ball bearings are used throughout, and the double pole switch of ample capacity is fitted with a retaining button. Armature and field windings are enamelled and double silk covered copper wire, and the armatures are dynamically balanced to highest precision limits by electronic methods.

The complete kit comprises the high speed DG1 grinder with 10 ft. of 3-core T.R.S. cable, spare set of carbon brushes, a carefully chosen set of mounted points, grinding wheels, and felt bobs and arbors, completely housed in a specially designed steel carrying case. This useful outfit provides an efficient method for grinding down contours, correcting inaccuracies in dies, light profile grinding, retouching taps, cutters and forming tools, etc. A wider selection of rotary files and milling cutters for use on non-ferrous metals is available to suit special requirements.

Wolf Electric Tools, Ltd.

High Conductivity Heat Resistant Sheet

For many years the high-strength, high-temperature alloy, developed under the name of Nimonic 75, has been widely used in sheet form for the combustion chamber linings in many British gas turbines. In this type of service the chief requirements of the metal are strength to resist distortion and cracking through the stresses arising from thermal expansion, plus high resistance to scaling. Nimonic 75 fulfils these needs to an adequate degree and, in addition, readily lends itself to normal fabricating, including argonarc and resistance welding. For some time, work has been going on to develop a material which would have the characteristic properties of Nimonic 75 but, at the same time, would have a much higher heat conductivity, in order to dissipate the heat of the combustion in the chamber more quickly, and secure a much more even temperature distribution in the chamber. Under the registered trade mark "Nimoply 75," Henry Wiggin & Co. Ltd., now announce the introduction of composite metal sheets, having Nimonic 75 on both sides of a copper base. This metal sandwich is produced by rolling copper between sheets of Nimonic 75, resulting in a clad sheet having many potential uses, not only in gas turbine construction but also in other fields of high-temperature engineering.

Henry Wiggin & Co., Ltd., Wiggin Street, Birmingham, 16.

CURRENT LITERATURE

Book Reviews

THE CONTROL OF QUALITY IN THE PRODUCTION OF WROUGHT NON-FERROUS METALS AND ALLOYS

I—The Control of Quality in Melting and Casting

Institute of Metals Monograph and Report Series. No. 15. Demy 4to, 88 pp., 16 plates and numerous other illustrations. Cloth boards. London, 1953. The Institute of Metals, 4, Grosvenor Gardens, S.W.1. 15s.

A feature of the Annual General Meeting of the Institute of Metals in recent years has been a symposium on some practical aspect of the production and fabrication of the non-ferrous metals and their alloys. In March, 1953, there was inaugurated a series of symposia on the control of quality in the production of wrought non-ferrous metals and alloys, the first one dealing with the melting and casting stages. This monograph, in its handsome blue binding, consists of a reprint from the Journal of the Institute of Metals of the papers presented at the symposium, together with the subsequent discussion.

Quality control of a sort has been practised for a long time, but the last decade has seen rapid strides made in the application of scientific methods to the problem. As Singer remarks in the introduction to the first paper presented to the symposium—on the principles of technical control in metallurgical manufacture—" A mere accumulation of experience from the past is of little use for planning action in a changed future, and the only way to resolve the difficulty is to extract principles from present and past experience, and use them as a guide for the further development of processes and techniques. Experience has shown that principles are more persistent in time than practice, and a good deal more reliable." The aim of Singer's paper is to outline some of the underlying factors operative in the technical control of quality and, where possible, deduce from them promising lines for future research and development. To this end, the effects of economic and technical factors on the quality of manufactured products are examined, and the characteristics of controlled processes analysed in terms of basic principles. Certain aspects of statistical control of plant are considered in relation to present practice and probable future developments.

Little more than a generation ago, brass casting was carried out with practically none of the technical control which is so extensively exercised to-day. During the last three or four decades, a wealth of knowledge has been accumulated regarding the effects which various factors have on the quality of castings, and the second paper, by Cook and Cowley, is mainly concerned with the application of basic principles and practical knowledge to the consistent production of high quality brass ingots and billets. Still dealing with copper base alloys, the paper by Sykes is confined to methods of control employed in melting and casting fire-refined copper, electrolytic copper, cadmium copper, tellurium copper, and silver-bearing copper. Some of the methods used to produce a sound casting are fairly general and applicable to other copper alloys not specifically mentioned.

In the production of zinc and zinc alloy rolling slabs and extrusion billets, two separate aspects of quality are involved. The castings must be such that they can be worked by normal methods, and they must also be suitable for the production of sheet, strip and extrusions with the required properties. In certain cases, these two requirements are in conflict, and, in consequence, the most suitable degree of compromise has to be adopted. The problems involved are discussed in the paper by Roberts and Walters, and it is concluded that, although certain defects can be associated with particular methods of casting, several methods are available whereby satisfactory slabs or billets can be produced, provided that supervision of the operations is adequate.

In the case of aluminium alloys, too, the fact that castings for subsequent working are made in alloys developed not primarily for their casting characteristics, but rather for their hot- and cold-working properties, gives rise to difficulties. Furthermore, the problems of successful manufacture are increased by the fact that the numerous alloy types produced are required in a wide diversity of cast forms. In the paper by Staples and Hurst, the best methods of quality control are considered in relation to nine standard groups of alloys intended for use in wrought forms. The other group of light alloys, based on magnesium, is discussed in the last paper, by Wilkinson and Hirst. Because, in the authors' works, working operations are not carried out on a commercial scale, it is more than ever important that effective quality control should be achieved; the inspection processes applied before the cast stock is sent out to other works are, therefore, crucial. A description is given of present practices in the control of quality and inspection in the melting and casting of the three principal types of magnesium alloy.

The volume is concluded with an account of the general discussion on the group of papers, followed by name and subject indexes.

Trade Publications

Aluminium Development Association Applications Brochure No. 6 " The Use of Aluminium Alloys in Structural Engineering," which first appeared in 1950 is an introductory survey to the subject designed to make known the characteristics and uses of aluminium to a fairly wide audience. An important characteristic of aluminium in the field of structural engineering is the facility with which structural sections can be produced by the extrusion process and a range of standard sections was published in B.S.1161 " Aluminium and Aluminium Alloy Sections." An addendum to Brochure No. 6 has just been published—" Bulbed and Lipped Structural Aluminium Alloy Sections (Angles and Channels) "—as a result of recent researches and the development of a range of new shapes to overcome certain problems inherent in their sections. Three sets of data are shown covering equal bulb angles, unequal bulb angles, and lipped channel sections. The publication concludes with some brief notes on the design data, including a comparison between the recommended strut curve for

a channel section with the usual Perry curve for the same material.

DUE, no doubt, to the satisfactory results obtained in the gas turbine field from the use of Nimonic 75 for combustion chamber linings, the Nimonic alloys are becoming well established in many fields where there is a need for a high-temperature oxidation-resistant material. The two alloys of the series which are most widely used in sheet form are Nimonic 75 and its modified form, Nimonic F. A new publication, issued by the manufacturers Henry Wiggin and Co. Ltd., Wiggin Street, Birmingham, 16, gives up-to-date information on the annealing and pickling of these alloys, replacing earlier fabricating instructions. It includes notes on temperatures for annealing, and furnace atmospheres, together with formulae of acid pickles and alkaline liquors, and details of salt bath descaling. Copies may be obtained from the Company.

A NEW leaflet has been issued by David Brown Corporation (Sales), Ltd., Machine Tools Division, Manchester, 3, dealing with the David Brown-Muir S25V gear shaving machine. An earlier leaflet referred to three machines, the S5, S10 and S25, but production of the first two of these has now ceased and the third machine has been re-designated the S25V. It is designed for the rapid vertical shaving of spur and single helical gears by the radial loading method, and is fitted with a fully automatic crowning unit.

IN a handsome 52-page brochure, Dyson and Co., Enfield (1919) Ltd., present a record of the firm's development in gravity and pressure die casting. The scope of the die casting industry has been widened considerably in recent years, and the process offers great economies in the rapid production of high quality complex castings, with great accuracy of dimensions, which require little or no subsequent machining operations. Guidance is given of the choice of material in zinc-, aluminium- and copper-base alloys and certain basic principles regarding design are discussed, whilst at the same time the importance of early consultation between designer and die caster is stressed. The Company maintains a small sand foundry for the production of prototype castings for trial and experimental work. The brochure concludes with a description of the production and finishing of castings, and reference is made to the facilities available for inspection and control.

A COMPREHENSIVE publication on the engineering properties of spheroidal graphite cast iron, issued by The Mond Nickel Co., Ltd., helps to establish the position of this material relative to other cast ferrous materials. The tensile strength of S. G. Iron is about double that of a high-duty flake graphite iron, with a distinct yield point markedly higher than that of malleable cast iron. Elongation is 1–5% in the as-cast condition and 10–25% in the annealed condition, and the elastic modulus, at 25 million lb./sq. in., approaches that of steel. This combination of high yield strength, high modulus and good elongation together signify that although S. G. Iron has sufficient ductility to permit twisting and bending, it is nevertheless stiff and rigid, and requires considerable force to cause permanent deformation. The publication includes a list of typical applications and a bibliography. Copies can be obtained free of charge from The Mond Nickel Co., Ltd., Sunderland House, Curzon Street, London, W.1.

THOUGH a complete grasp of any technical subject can only be obtained through prolonged study, both in the laboratory and in the field of application, it is possible to demonstrate basic principles graphically and quickly through the medium of moving pictures supported by a lucid commentary. With this object in view, High Duty Alloys Ltd., have embarked on a series of films about the engineering possibilities of Hiduminium. Their purpose is primarily to show, as quickly as possible, what sort of characteristics Hiduminium possesses, the numerous ways in which it can be fabricated, and how its useful properties can be applied in engineering. Each of the films will be accompanied by its companion booklet, briefly outlining and illustrating the salient features. The first of these, dealing with the design characteristics of aluminium alloys has recently appeared.

THE making of a file still calls for the exercise of craftsmanship, and Sanderson Brothers and Newbould, Ltd., Sheffield, having been in this particular line of business for more than a hundred years, the processing in the S.B. & N. file department is in the hands of craftsmen with many years collective experience of the work. In a recently published booklet, some of these men are seen at work on various stages in the manufacturing procedure. The main part of the publication is devoted to descriptions of the standard files available from the Company.

Books Received

" Chromium "—Metallurgy of the Rarer Metals No. 1. By A. H. Sully, Ph.D., M.Sc., F.Inst.P., F.I.M. 272 pp. including numerous illustrations and index. London, 1954. Butterworths Scientific Publications. 35s. net. By post 1s. extra. The American edition of this book is published by Academic Press, Inc., 125 East 23rd Street, New York, 10.

" Zirconium "—Metallurgy of the Rarer Metals No. 2. By G. L. Miller, Ph.D., B.Sc., A.R.I.C., M.I.Chem.E. 382 pp. including numerous illustrations and index. London, 1954. Butterworths Scientific Publications. 45s. net. By post 1s. 6d. extra. The American edition of this book is published by Academic Press, Inc., 125 East 23rd Street, New York, 10.

" Protective Atmospheres." By A. G. Hotchkiss and H. M. Webber. 341 pp. including numerous illustrations and index. New York and London, 1953. John Wiley and Sons, Inc., and Chapman and Hall, Ltd. 56s. net.

" Die Metallischen Werkstoffe Des Maschinenbaues." By Dr.-Ing. E. Bickel. 442 pp. including 456 illustrations. Berlin, Göttingen and Heidelberg, 1953. Springer-Verlag. Ganzleinen DM.37·50.

" Metallurgical Dictionary." By J. G. Henderson, assisted by J. M. Bates, B.Sc., Met. Eng. 396 pp. New York and London, 1953. Reinhold Publishing Corporation and Chapman and Hall, Ltd. 68s. net.

" Modern Electroplating." Edited by Allen G. Gray. (The Electrochemical Society Series.) Sponsored by The Electrochemical Society, Inc. 563 pp. including appendix and index. New York and London, 1953. John Wiley and Sons, Inc., and Chapman and Hall, Ltd. 68s. net.

LABORATORY METHODS
MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS

FEBRUARY, 1954 Vol. XLIX, No. 292

The Application of the Complexones in Metallurgical Analysis

By E. G. Brown, A.M.C.T., F.R.I.C.

Since 1945, considerable attention has been given, particularly by Czechoslovak workers, to the application of the complexones in analytical chemistry, and good progress has been made in their use in certain fields, notably water analysis. In this survey the author refers to specific proposals for the use of complexones in metallurgical analysis, this first part dealing with the ferrous field.

THE systematic investigation of the "Complexones," by Schwarzenbach and his school, ushered in a new era in chemical analysis, the use of ethylenediamine tetra-acetic acid and allied compounds. Since 1945[1], many papers have appeared on the application of the complexones in analytical chemistry; the bulk of these are due to Pribil[2] and his collaborators in Czechoslovakia and, to a lesser extent, to Flaschka in Austria, who has a survey of the literature up to the end of 1952[3] in course of publication. Belcher[4] considers that ethylenediamine tetra-acetic acid is, perhaps, the most outstanding reagent ever applied in analytical chemistry.

Most of Pribil's work is concerned not only with the theoretical aspects of the analytical applications of the complexones but also, as befits the present character of Czechoslovak analytical chemistry, with the practical solution of many difficult problems in the analysis of complex materials. Of these, the investigation of minerals, ores, metals and alloys plays a large part. The purpose of the present article is to review the application of the complexones in metallurgical analysis; the aspect of mineral and ore determinations will be considered elsewhere. The paper is divided into two parts—ferrous and non-ferrous. In general, the uses of the complexones in analysis may be divided into four categories: (*a*) masking action, (*b*) colorimetric analysis, (*c*) titrimetry, and (*d*) polarography. Examples will be given of all these functions in the field of metallurgical analysis.

For convenience, the following nomenclature due to Schwarzenbach will be adopted in the naming of the complexones in this article: nitrilotriacetic acid—Complexone I; ethylenediamine tetra-acetic acid—Complexone II; disodium dihydrogen ethylenediamine tetra-acetate—Complexone III.

FERROUS APPLICATIONS

Cobalt

Pribil and Malicky[5] showed that bivalent cobalt forms a stable complex with ethylenediamine tetra-acetic acid, which by dissociation forms the bivalent anion $Co^{II}Y^{-2}$ (Y = ethylenediamine tetra-acetate anion). Tervalent cobalt also forms a stable, violet-coloured complex, and the corresponding monovalent anion $Co^{III}Y^{-1}$. Oxidation can thus be shown

$$Co^{II}Y^{-2} \rightarrow Co^{III}Y^{-1} + e$$

and the potential of this system by

$$E = E_0 - 0{\cdot}059 \log_{10} \frac{[CoY^{-2}]}{[CoY^{-1}]}$$

The normal potential of the system Co^{+3}/Co^{+2} is very high, at $+1{\cdot}79$ volts, whereas for the new system CoY^{-1}/CoY^{-2} a value of $+0{\cdot}60$ volts is obtained (depending on the *p*H of the solution). This is an illustration of the general principle that the formation of complexes in a redox system lowers the potential of that system. Consequently, cobalt^{II} can be oxidised in acid solution by a sufficiently strong oxidising agent, so long as it is initially complexed with Complexone II: ceric sulphate has been found to be suitable. The excess of complexone is bound by calcium ions (otherwise free ethylenediamine tetra-acetic acid separates out), and the titration is subsequently carried out in neutral solution. The method is applicable in the presence of copper^{II}, chromium^{III}, zinc, aluminium, iron^{II}, magnesium and calcium: manganese and nickel interfere and must be removed.

Pribil states that the method was used for cobalt steels with usually satisfactory results, but he gives no details of his experiments. In general, the determination, although of great theoretical interest, has several unsatisfactory features, and in a further communication, Pribil and Svestka[6] describe a more satisfactory method for cobalt determination.

Cobalt is oxidised in the presence of complexone by ceric sulphate at 60° C.; the excess oxidant is then reduced by the excess complexone and the cobalt complex is subsequently quantitatively reduced by chromous chloride in acid solution at the same temperature, the end-point being indicated potentiometrically. If manganese is present, ceric sulphate must be replaced by potassium dichromate, as the ceric salt does not oxidise cobalt quantitatively in the presence of manganese. The final method evolved is applicable in the presence of manganese, zinc, nickel, chromium and aluminium: molybdenum^{VI} and vanadium^{V} interfere, but small amounts of tungsten do not. Procedures for the simultaneous determination of both cobalt and iron are described. Pribil and Svestka[6] applied their method to cobalt steels containing from about 1·4 to 16% of

TABLE I.—DETERMINATION OF COBALT IN STEEL.

Steel	Composition—%											Determination No.	Cobalt Found %
	C	Mn	Si	P	S	Cr	W	Ni	Mo	V	Co		
I	0·34	0·53	1·77	0·015	0·007	1·00	0·64	2·34	—	—	1·42	1 2 3 4	1·46 1·43 1·43 1·44
II	0·71	0·11	0·26	—	0·012	4·30	18·05	—	0·69	1·45	4·80	1 2 3 4	4·88 4·77 4·79 4·73
III	0·65	0·17	0·28	—	0·023	4·17	17·10	0·06	0·67	1·80	16·00	1 2 3 4	16·05 16·02 16·04 16·12

cobalt, after initial removal of the iron with zinc oxide. The results obtained are quoted in Table I.

The French authors Souchay and Faucherre[7, 8] noticed in 1948 that a solution of cobalt[II], buffered with acetic acid, was oxidised by lead dioxide, in the presence of ethylenediamine tetra-acetic acid, to an intense rose-violet colour, as independently observed by Pribil and Malicky[6]. They proposed the reaction for a colorimetric determination of cobalt but published no details. The quantitative application of the observation was worked out by Jean[9, 10] who applied the procedure to the determination of steels containing over 2% of cobalt and up to 16·7%.

Jean replaced lead dioxide by hydrogen peroxide and worked in an oxalate-fluoride-phosphate medium. The usual alloying elements of steel—manganese, copper, nickel, chromium, molybdenum, tungsten, vanadium and titanium—do not interfere with the cobalt determination. For amounts of cobalt over 2%, the usual zinc oxide separation procedure is not necessary: but for less than 2% cobalt it is. The final colour is measured on a spectrophotometer at 546mμ, after development of the complex by warming. Very good results are claimed for the procedure, which is part of an investigation of new reactions of cobalt and their development for the analysis of ferrous metals—especially high-speed steels.

Pribil and Malik[11] have independently described the colorimetric determination of cobalt using complexone, anticipating that of Jean[10], who was apparently unaware of the work of the Czech authors. The method is applied to the analysis of steels but, unfortunately, details are lacking, as the paper has as yet only appeared in the Czech language.

The main purpose of the paper of Souchay and Faucherre[7] quoted above is a study of ethylenediamine tetra-acetic acid as a new base solution in polarography. The authors show that complexone strongly reduces the reduction potentials of numerous elements; owing to its ready transformation to the tervalent state, cobalt may be determined without preliminary separation in the presence of an excess of most other metals (especially nickel), because it is then reduced at a very much lower potential (about +0·2 V.) than in the usual bivalent form (> 1·0 V.). Iron[III] interferes, but is eliminated by the use of a pyridine-pyridine hydrochloride buffer, which precipitates ferric hydroxide in a non-adsorbing form that is easy to filter. Cobalt is determined polarographically in steel containing copper, nickel, etc., by the use of lead dioxide as an oxidising agent for cobalt[II] to cobalt[III], in the presence of the potassium salt of ethylenediamine tetra-acetic acid as a base solution. No results are quoted.

Chromium

Pribil and Sykora[12] have demonstrated the possibility of using the complexones in iodometric analysis, and worked out a procedure for the iodometric determination of dichromate, bromate or iodate in the presence of iron[III] and copper.[II] Interference by these cations can be eliminated by the use of ethylenediamine tetra-acetic acid. Under suitably modified conditions, the iodometric determination of chromium[VI] can be carried out in the presence of vanadates, permanganates, molybdates and cerium[IV]. The method has been applied to the determination of chromium in steels, but details are not available. In a further communication, Pribil, Simon and Dolezal[13] have described the iodometric determination of cerium[IV], permanganate and chromate (or dichromate) in the presence of tervalent iron and bivalent copper. After reduction of the ions named by iodide, the ferrous ions or cuprous iodide formed are converted into stable complexes by the addition of Complexone III; these complexes are immediately oxidised by the iodine present. The excess iodine, which is equivalent to the amount of cerium (permanganate, chromate, dichromate) is back-titrated with sodium thiosulphate.

This method is proposed for the rapid determination of cerium alloyed with iron, after oxidation with potassium persulphate. The iodometric determination of cerium according to

$$2Ce^{+4} + 2I^{-1} \rightarrow 2Ce^{+3} + I_2$$

is rarely carried out because iron interferes, but the procedure is very satisfactory by the complexone method. Similarly, manganese[VII] can be titrated in the presence of iron, e.g., in alloys, after initial oxidation of iron with ammonium persulphate. The method also shows advantages over the original procedure of Pribil and Sykora[12] in the determination of chromium.

The complexometric application of the determination of chromium in steels has been described by Pribil and Klubalova.[14] They point out that most methods for the colorimetric determination of small amounts of chromium are based on the oxidising action of chromates, and not on complex formation, and require very careful control of experimental conditions. When chromium[III] is warmed with ethylenediamine tetra-acetic acid (Complexone III) an intense purple complex is formed, which is suitable for the colorimetric determination of the element. In practice, it is best to work in either a neutral or a slightly acid solution, to boil the solution five minutes with 5 ml of 5% complexone solution, and to measure the absorption at 550 mμ. The figure quoted for the lower limit of detection is 0·1 mg. in 100 ml.

Elements such as calcium, magnesium, aluminium, zinc and manganese do not interfere, but iron, nickel

cobalt and copper form coloured complexes, and are removed as hydroxides in alkaline solution in the presence of hydrogen peroxide, whereby chromium^{III} is converted to chromate. Pribil and Klubalova[14] state that chromate must always be reduced back to chromium^{III} by complexone itself, otherwise variable results are obtained. The method is applied to alloy steels by the following procedure.

A suitable amount of the sample was dissolved in hydrochloric acid and the tungsten and molybdenum present precipitated by several evaporations. After extraction of the residue with water, iron, nickel and cobalt were precipitated as the hydroxides by the addition of potassium hydroxide and hydrogen peroxide. This operation was carried out twice more if necessary. To an aliquot part of the filtrate, 5 ml. of 5% complexone and 2 ml. of a 0·1% solution of manganese sulphate were added, and, if necessary, the solution was neutralised with hydrochloric acid. It was then brought to the boil for 5 minutes. After cooling, its volume was made up to 100 ml. and colorimetric readings taken on the Lange colorimeter, using a green filter and cells of 34 mm. depth. The results obtained by Pribil are shown in Table II.

TABLE II.—DETERMINATION OF CHROMIUM IN STEEL.

Steel	Chromium Content %	Determination No.	Chromium Found %	Difference %
I	1·00	1	1·03	+ 0·03
		2	1·03	+ 0·03
		3	0·95	− 0·05
II	4·30	1	4·19	− 0·11
		2	4·10	− 0·20
		3	4·33	+ 0·03
III	4·20	1	4·30	+ 0·10
		2	4·14	− 0·06
		3	4·11	− 0·09
IV	0·17	1	0·16	− 0·01
		2	0·164	− 0·006
		3	0·162	− 0·008

Copper

The Czech authors Sedivec and Vasak[15] have improved the selectivity of the well-known determination of copper with sodium diethyldithiocarbamate. As usually practiced, elements such as nickel, cobalt, manganese and iron interfere in the method. However, in the presence of Complexone II, these cations are converted into stable complexes, unaffected by sodium diethyldithiocarbamate. Hence the selective colorimetric determination of copper, after extraction into ethyl acetate, is possible. Only mercury, lead, cadmium, silver and bismuth interfere : the first three carbamate complexes are white and form colourless solutions in organic solvents, and only the solutions of the bismuth and silver carbamates in organic solvents are yellow.

The method is applied to steels, without any need for preliminary separation with hydrogen sulphide, in the following manner. A 1 g. sample of the steel is dissolved in nitric acid, and any silicic acid deposited is filtered off. The filtrate is made up to 250–1,000 ml. in a graduated flask, according to the copper concentration. To 50 ml. of the diluted solution, 0·5–1·5 g. of complexone are added, the solution made alkaline with ammonia, and the copper extracted into ethyl acetate after conversion to the diethyldithiocarbamate complex. The colorimetric determination is carried out as previously described. Table III details a typical result.

TABLE III.—DETERMINATION OF COPPER IN STEEL.

Steel Composition—%							Copper Found %
C	Mn	Si	Cr	Ni	Mo	Cu	
0·05	0·53	0·93	18·54	9·43	1·77	0·71	0·71

A similar method to that of Sedivec and Vasak for the determination of copper in iron and steel was subsequently described by the American workers, Hague, Brown and Bright[15].

Manganese

The reductometric determination of tervalent manganese is described by Pribil and Horacek[16]. This estimation is usually affected by oxidation of manganese^{II} to manganese^{VII} with sodium bismuthate or ammonium persulphate, and subsequent titration of this permanganate with ferrous sulphate. Pribil and Horacek observed that Complexone III masks most elements interfering in this determination. In work on the determination of cobalt, Pribil and Malicky[5] found that oxidation of manganese by ceric sulphate, potassium dichromate, etc., was incomplete in the presence of complexone, and then studied the use of insoluble oxidants such as sodium bismuthate and lead dioxide. These had the advantage that excess could be removed by filtration. Sodium bismuthate functions slowly, but lead dioxide quickly, even in cold solution, yielding the somewhat unstable manganese complexonate in the presence of acetic acid and calcium acetate. The excess of lead dioxide is removed by filtration on a sintered glass crucible, but large amounts make filtration difficult. Titration is to be carried out within five minutes of oxidation, and the end-point is determined potentiometrically with ferrous ammonium sulphate. Iodometric determination of manganese complexonate is also possible.

Copper, lead, zinc, nickel, aluminium and chromium do not interfere, but cobalt, tungsten and molybdenum do. Large amounts of phosphate and sulphate are undesirable, and bromides must be absent. Mineral acid also interferes, and the procedure is thus carried out in an acetic acid medium.

The procedure has been applied to the analysis of manganese in steels, but with no better results than the commonly used Procter-Smith method : no details are given. However, the procedure was applied to the determination of manganese in ferromanganese with good results.

A suitable amount of sample was dissolved in a small amount of diluted nitric acid, and the oxides of nitrogen boiled out. After neutralising with caustic soda, the solution was quantitatively transferred to a 100 ml. volumetric flask, and filled to the mark with water. In a suitable portion of such a prepared solution, oxidation of manganese was performed, and the manganicomplexonate formed determined potentiometrically by ferrous sulphate. The results are quoted in Table IV.

TABLE IV.—DETERMINATION OF MANGANESE IN FERROMANGANESE

Ferro-Manganese	Composition—%							Determination No.	Manganese Found %
	C	Si	P	S	Cu	Fe	Mn		
I	1·0	—	—	—	—	16·6	82·30	1	81·66
								2	81·20
								3	81·85
II	5·76	2·30	0·31	0·032	0·10	—	67·1	1	66·76
								2	66·76
								3	66·68

The oxidimetric determination of manganese by means of ferricyanide is detailed in a further communication by Pribil and Simon[17]. The principle of this method is an adaption of the paper of Tomicek, Sandl and Simon,[18] who were able to carry an oxidimetric determination of manganese to its higher valency state by ferricyanide in the presence of strong ammonia, ammonium chloride or carbonate and potassium cyanide. This determination was, unfortunately, invalidated by elements which cannot be held in a complex in an alkaline medium, e.g., iron and titanium, and by the presence of cobalt, which was simultaneously oxidised.

Pribil and Simon[17] made use of Complexone III to determine manganese even in the presence of cobalt and iron. The complexes formed with bivalent manganese and bivalent cobalt are easily oxidised by potassium dichromate, but the tervalent manganese complex is much less stable than the tervalent cobalt complex. In hot solution, potassium dichromate can be reduced by Complexone III, manganese^{III} complexonate is unstable and is reduced to manganese^{II} complexonate, whilst the cobalt^{III} complexonate is stable. Thus, in determining manganese in the presence of cobalt, cobalt^{III} and manganese^{II} are oxidised by dichromate in the presence of excess Complexone III in hot solution; excess oxidant is thereby reduced and forms a stable chromium^{III} complexonate. The resultant solution, containing all the cobalt in the tervalent state, is added to a solution containing ammonium chloride, ammonia, potassium cyanide and calcium chloride. Cobalt^{III} complexonate then forms cobalticyanide, and bivalent manganese now exists partly as manganocyanide and manganocomplexonate. The excess calcium ions convert manganese completely into manganocyanide, due to the combining of calcium ions with the complexonate of manganese^{II}. The manganocyanide is now titrated by the above ferricyanide method, using a potentiometric end-point in the absence of oxygen.

Iron^{III} interferes with the determination of manganese by this procedure, due to the formation of the ferricyanide complex. However, iron^{II} does not interfere if bound with complexone, thus interference is avoided by reduction of ferric iron with zinc in the presence of complexone, so long as no cobalt is present. In this eventuality, nascent hydrogen reduces the cobalt^{III} complexonate and reduction of iron^{III} to iron^{II} must be done by sodium sulphide.

Pribil and Simon apply the procedure to the determination of manganese in ferromanganese in the following manner. 1 g. of sample is dissolved in 10 ml. of concentrated nitric acid and evaporated to dryness, the last traces of acid being removed by gentle heating. The residue is dissolved in 20 ml. of concentrated hydrochloric acid, transferred into a 100 ml. flask and made up to the mark. From the solution, according to the content of manganese, 10–25 ml. are pipetted off and adjusted to the titration. Excellent results are obtained, as will be seen from Table V.

Pribil and Hornychova[19] have worked out a procedure for the colorimetric determination of manganese depending on the formation of a ruby-red complex with ethylenediamine tetra-acetic acid but the method has not been applied to metallurgical analysis.

Molybdenum

Pribil and Malat[20] have studied the influence of 8-hydroxyquinoline (oxine) on the complexes formed between ethylenediamine tetra-acetic acid and a number of cations. In the presence of Complexone II, in acetic acid—ammonium acetate medium, oxine only precipitates molybdenum^{VI}, tungsten, uranium^{VI} and vanadium^{V}, other cations being completely screened. Quantitative separation of molybdenum from copper, lead, cadmium, mercury^{II} and bismuth can be effected. If the filtrate from this determination is buffered with sodium acetate and ammonia, the copper oxinate compound may be quantitatively precipitated. Iron^{III} and aluminium behave similarly.

TABLE V.—DETERMINATION OF MANGANESE IN FERROMANGANESE

Ferro-manganese	Composition—%							Determination No.	Manganese Found %	Average
	C	Si	P	S	Cu	Fe	Mn			
I ..	1·0	—	—	—	—	16·6	82·3	1	82·28	82·23
								2	82·36	
								3	82·11	
II ..	5·76	2·30	0·31	0·032	0·10	—	67·1	1	66·80	66·81
								2	66·56	
								3	67·06	

On the basis of these facts an analysis of ferromolybdenum was proposed, involving the simultaneous precipitation of molybdenum and iron. 3–4 g. of the sample were taken up in concentrated nitric acid to which a small amount of hydrochloric acid had been added. The insoluble residue was filtered off, washed thoroughly with hot water and the combined filtrate and washings made up to 500 ml. in a calibrated flask. 5–20 ml. of the solution were pipetted off, diluted to about 80 ml. and, after the addition of complexone, neutralised by means of ammonia to methyl orange. After the addition of 3–4 ml. of acetate buffer, the warm solution was precipitated by means of 8-hydroxyquinoline. Iron may be simultaneously determined, in faintly ammoniacal solution, also as oxinate.

Determination of molybdenum as $PbMoO_4$ gave 74·78% Mo in the alloy (average of 3 determinations). Results by the oxine method averaged 74·74% Mo.

Nickel

The American workers Harris and Sweet[21] have applied a volumetric complexometric procedure to the determination of nickel in various types of steel. They point out that while the gravimetric determination of nickel as the dimethylglyoxime complex is widely used, several volumetric modifications have been proposed. In the present estimation, nickel is separated in the usual way with disodium dimethylglyoxime, and the resultant complex dissolved in hydrochloric acid. This solution is evaporated nearly to dryness to remove ammonium salts, diluted and ammonia added until the blue colour of the nickel complex is given. Murexide indicator is added, and the solution titrated with a standard solution of disodium ethylenediamine tetra-acetate to the change from yellow to purple, according to the original observation of Schwarzenbach and Gysling.[22]

TABLE VI.—DETERMINATION OF NICKEL IN IRON AND STEEL.

Material	Nickel Content (N.B.S. value) %	Nickel Found % (mean)
Nickel-Chromium Cast Iron	1·00	0·999
Nickel-Chromium Steel	1·19	1·19
Nickel-Chromium Steel	1·20	1·20
Nickel-Molybdenum Steel	1·81	1·84
Nickel Steel	3·28	3·28
Nickel-Chromium-Molybdenum Steel	8·91	8·90

Several advantages are claimed for the method over conventional applications ; copper, cobalt[11], manganese, chromium and iron do not interfere. Experiments are detailed with regard to nickel-chromium cast iron, nickel-chromium steel, nickel-molybdenum steel, nickel steel and chromium-molybdenum-nickel steel, containing 1–9% of nickel, with very good results (see Table VI).

Flaschka[23] has criticised the method of Harris and Sweet as being very slow. He suggests a method based on the fact that the nickel dimethylglyoxime complex is not precipitated from an ammoniacal solution containing disodium dihydrogen ethylenediamine tetra-acetate. The nickel complex is thus precipitated in the usual way, filtered, washed and dissolved in hot dilute hydrochloric acid. An excess of Complexone III solution is added to the acid filtrate, which is then neutralised with ammonia. Buffer solution (ammonia-ammonium chloride) is added, and the excess complexone is titrated with standard zinc solution, until the Eriochrome Black T indicator changes from blue to red. Alternatively, to avoid the need for two standard solutions, potassium magnesium complexonate is added to the acid nickel solution. On buffering, magnesium ions are liberated, and these are titrated in the usual way with Complexone III and Eriochrome Black T. This method is especially recommended for micro-titrations.

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To be continued

Mounting Thin Strips for Metallographic Examination

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THE mounting of 0·020 in. thick sheets for metallographic examination frequently presents certain difficulties. Methods which have been tried in the author's laboratory include gripping sheets between mild steel clamps, and drilling and bolting the specimen between two end pieces. These methods are not entirely successful. They are not only time consuming, but suffer from the disadvantage that, since the sheets are rough and may not be perfectly flat, water and etching reagent are inevitably trapped between the sheets. The polished surface then becomes stained. The insertion of a soft strip of metal between the sheets and compressing by means of the clamp does not always overcome this effect. Moreover, pitting or spurious etching effects may arise throught electrolytic action between the specimens and the soft packing metal.

A simple method of overcoming these difficulties has been devised. The sheets are held between the coils of a light tension spring, as shown in Fig. 1. The pack of specimens can readily be positioned on the base of the die for mounting in bakelite. Since each sheet will be completely surrounded by mounting compound, difficulties due to staining are greatly reduced. There may be a tendency for the pack of specimens to tilt slightly during the compression and heating of the moulding compound. If this is undesirable, it is best to surround the pack with a steel ring, e.g., a short length of electrical conduit, before adding the powder to the die. Recently a mounting plastic has become available[1] which is ideal for use in combination with the above method. The plastic will harden at 100° C. under a low pressure, but satisfactory mounts can be made without applied pressure by allowing the mount to harden at room temperature. The thin sheets are wetted by the plastic, so that staining after etching is greatly reduced. Furthermore, there is no risk of causing the pack of specimens to tilt.

1 P. A. Lovett, *Metal Industry*, 1953, **83**, 70.

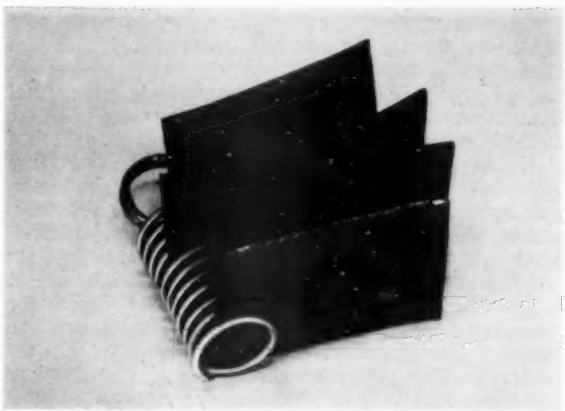

Fig. 1 × 1½ approx.

The author is indebted to Dr. T. Emmerson, Director of Research, G.K.N. Group Research Laboratory, for permission to publish this communication.

Change of Address

ELLIOTT BROS. (LONDON) LTD., announce the transfer of their Manchester Office to premises at 66, Deansgate, Manchester, 3 (Telephone : BLAckfriars 7752), Fisher-Governor Co. Ltd., who are associates of Elliott Bros. will also operate from this address.

Northern Aluminium Co. Ltd. announce that the telephone number of their Leeds Area Sales Office is now : Leeds 33621.

Determination of Iron in Ores, Slags and Refractories

One of the subjects which has recently occupied the attention of the Methods of Analysis Committee of the British Iron and Steel Research Association is the determination of iron in ores, slags, refractories and similar materials. In this summary of the work, reference is made to the stannous chloride and hydrogen sulphide methods, and to an absorptiometric method for iron contents below 3 per cent.

RECENT work by the Methods of Analysis Committee of B.I.S.R.A. has been concerned with the determination of iron in a variety of materials, such as ores, slags and refractories. The following note summarises the majority of this work.

Two volumetric methods have been examined and their scope and limitations defined. One method makes use of stannous chloride and the other of hydrogen sulphide for the reduction of ferric iron to ferrous iron. In either case, a dichromate titration of the ferrous iron is made, using diphenylamine sulphonate as the internal indicator. Modifications of the hydrogen sulphide method have been applied to materials containing small amounts of iron, and an absorptiometric procedure is recommended for use when there is less than 1% of iron.

Stannous Chloride Method

The first stage of the enquiry determined the best conditions for the use of this method. Tests were carried out to define the effects of elements which might be present, either in the original sample or in the final solution when ready for titration. It was found that the method gave erroneous results in the presence of platinum, molybdenum, copper, vanadium and large amounts of phosphate or nitrate. It was, however, entirely satisfactory for relatively pure iron solutions, and the results of its application to a wide selection of blast furnace raw materials and slags, steel-making slags and refractories are tabulated in B.I.S.R.A. report MG/D/23/52* which may be obtained from the Association. For example, twelve tests on twelve iron ore samples and twelve miscellaneous samples are recorded. The difference between the determinations was, except for very complex samples, always less than 1% of the amount of iron present.

Hydrogen Sulphide Method

This method was developed out of the use of hydrogen sulphide to remove the interfering elements in the stannous chloride method. Although it was realised that hydrogen sulphide would also reduce ferric iron, it was at first thought that treatment with stannous chloride would still be needed, but this was found not to be so. The method of using hydrogen sulphide as the sole reducing agent is less simple, but it overcomes interference from other metals, and is recommended strongly as the standard method for the determination of major contents of iron. The method is, however, impeded if large amounts of phosphate, nitrate, fluoride or chloride are present. Phosphoric acid must not be used in the initial solvent, but may be added after the reduction of the ferric iron. The other three acid radicals are easily removed by fuming with sulphuric or perchloric acid before the reduction.

* *Jnl. Iron & Steel Inst.*, 1952 (August), **171**. 392—403.

Determination of Iron in Miscellaneous Samples

Trials carried out on a wide variety of substances have shown that different procedures are needed to obtain complete decomposition. The report concludes that the most satisfactory method of decomposing samples for the determination of iron is by acid attack; most iron and steel-making raw materials, slags and refractories, which contain sufficient iron to warrant a volumetric determination, are largely soluble in some mineral acid or mixture of acids. Even samples containing a substantial proportion of constituents insoluble in acid are best given a preliminary acid treatment to reduce the amount of material which has to be decomposed by other means. In all work of high accuracy, the insoluble residue from the preliminary acid attack should be subjected to a further decomposition, for which bisulphate fusion in a silica crucible is generally satisfactory.

Determination of Iron below 3%

Two methods have been investigated. First, the hydrogen sulphide volumetric method adapted in order to achieve greater precision; and second, an absorptiometric method which is based on the colour reaction of ferrous ions with thioglycollic acid in ammoniacal citrate solution. These two methods were applied to a blast furnace slag, a silica brick and a sillimanite brick. The results obtained from eleven separate tests clearly show that both methods give satisfactory results for iron contents below 1%.

Correspondence

The Editor, METALLURGIA,

Sir,

A RAPID COMPLEXIMETRIC METHOD FOR THE DETERMINATION OF MAGNESIUM IN ALUMINIUM ALLOYS

In the paper under the above-mentioned heading by Mr. J. Sergeant, published in the November, 1953, issue of METALLURGIA, due acknowledgment to the Alar Chemists' Committee, Mr. L. H. Wadsworth of Enfield Rolling Mills, and Mr. R. C. Jackson of Eyre Smelting Co., was inadvertently omitted.

Independent of and after the start of this investigation, the method was discussed at Alar Chemists' Meetings, and the outcome of these, and Members' experience, was available to us during completion of the work.

In view of this, the omission is regretted and acknowledgment is gladly given.

Yours faithfully,

E. A. Gilbert,

Head of T. J. Priestman Laboratories.

Birmingham. 22nd January, 1954.